GEOTHERMAL RESOURCES OF UTAH
A Digital Atlas of Utah's Geothermal Resources

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CONVERSION FACTORS

Length:	1 centimeter (cm) = 0.3937 inch (in.) 1 meter (m) = 3.281 feet (ft) 1 kilometer (km) = 0.6214 mile (mi)
Area:	1 m^2 = 10.76 ft^2 1 km^2 = 0.3861 mi^2
Volume:	1 liter (L) = 0.2642 gallon (gal) 1 km^3 = 0.2399 mi^3
Mass:	1 kilogram (kg) = 2.205 pounds (lb)
Flow Rate:	1 liter per minute (L/min) = 0.26417 gallon per minute (gal/min) 1 ft^3/second (cfs) = 1,699 liters per minute (L/min)
Temperature:	degrees Celsius (°C) = 5/9 (degrees Fahrenheit [°F]-32) Kelvins (K) = °C+273.15
Temperature gradient:	1°C/km = 0.05486°F/100 ft
Energy:	1 joule (J) = 0.2390 calorie (cal) 1 J = $9.485x10^{-4}$ British thermal unit (Btu) 1 J = $2.777x10^{-4}$ watt-hour (W hr) 10^{18} J = 0.9485 quad (10^{15} Btu)
Power or work:	1 watt (W) = 1 J/s 1 megawatt (MW) = $3.154x10^{13}$ J/yr
Heat flow:	1 mW/m^2 = $2.390x10^{-8}$ cal/cm s 1 mW/m^2 = $2.390x10^{-2}$ heat-flow unit (HFU)
Thermal conductivity:	1 W/m K = 2.390 mcal/cm s °C

ABSTRACT

Many researchers have studied geothermal resources in Utah over the past few decades, largely the result of federal and state cooperative projects. Because no summary from these efforts had been compiled since the publication of a state geothermal resources map in 1980, the Utah Department of Natural Resources and the Utah Department of Community and Economic Development jointly sponsored a project to prepare a statewide review-summary of geothermal resources. The summary is presented as an interactive computer-driven product employing geographic information system technology and other computer software to present detailed, spatially related data on all known geothermal resource areas in Utah. In this report, we review the nature of geothermal systems throughout the four principal physiographic regions of Utah and the relationship to geologic setting, recent faulting, and young igneous rocks. A technical database, UTAHGEO.dbf, contains nearly 3,000 records pertaining to more than 1,100 thermal wells and springs in Utah and is included as part of the GIS data. Descriptions of all known thermal areas in Utah are presented. Crustal heat-flow in Utah, included as a companion report, is also presented.

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INTRODUCTION

As part of a U.S. Department of Energy, state-cooperative geothermal program in the late 1970s, the Utah Geological Survey (UGS) compiled a geothermal resources map of Utah (Utah Geological and Mineral Survey, 1980). Published in 1980, the "Geothermal Resources of Utah" map was compiled using geothermal and water-resource data from existing publications and other data sets. The information presented on the map was of a general nature; however, the map was very useful because it showed locations of thermal wells and springs and listed individual source temperatures, water-quality data, and flow rates. The map also outlined areas of prospective value for geothermal resources, and provided descriptive information about individual geothermal areas. It was published through the U.S. National Oceanic and Atmospheric Administration and was made widely available free of charge. As a result, stores of the map quickly dwindled. Presently, the 1980 map is available only through libraries.

Since the publication of the Utah geothermal resources map in 1980, various workers completed a number of geothermal-related studies, the result of federal, state, and privately funded research. In addition to regional and statewide resource assessments, such as reported in Blackett (1994), Budding and Bugden (1986), and Mabey and Budding (1987), the projects also involved detailed analyses of individual geothermal areas. Due to the recent increase in economic and environmental interest in geothermal systems, the Utah Department of Natural Resources (Utah Geological Survey and the Office of Energy and Resource Planning) and the Utah Department of Community and Economic Development initiated a cooperative project to produce a new, interactive, digital map and report using geographic information system (GIS) technology to be published on compact disk (CD-ROM). The information on this CD-ROM contains technical data on geothermal resources in Utah for scientists and engineers, based on all of the past federal- and state-funded, geothermal-related efforts. It also contains this interactive report for the general user.

Various GIS themes, or coverages, are included at a statewide scale of 1:500,000 although some themes were compiled at more detailed scales. The CD-ROM includes software to view, manipulate, and print the various GIS themes, and also includes a user-guide along with interactive documents. Among other items, these documents contain the GIS-generated geothermal map of Utah with links to supporting text, database, and image files.

OVERVIEW OF GEOTHERMAL RESOURCES

Nature of Geothermal Energy

As described in Wright and others (1990), geothermal energy is the heat that originates within the earth. The earth is an active thermal engine. Many of the large-scale geological processes that have helped to form the earth's surface features are powered by the flow of heat from inner regions of higher temperature to outer regions of lower temperature. The mean value of the surface heat flow for the earth is 1.32×10^{13} J/yr (42 million megawatts [MW]) (Williams and Von Herzen, 1974), which represents heat that comes to the surface and is lost by radiation into space. Generation of new oceanic crust at spreading centers such as the mid-Atlantic ridge, motion of the great lithosphere plates, uplifting of mountain ranges, release of stored strain energy by earthquakes and eruption of volcanoes are all powered by the outward transport of internal heat. Plastic, partially molten rock at estimated temperatures between 600°C and 1,200°C (1,100°F and 2,200°F) is postulated to exist everywhere beneath the earth's surface at depths of 100 km (60 mi) or less. By comparison, using present technology applied under favorable circumstances, holes can be drilled to depths of about 10 km (6.2 mi), where temperatures range upward from about 150°C (300°F) in average areas to perhaps 600°C (1,100°F) in exceptional areas.

Exploitable geothermal resources originate from transport of heat to the surface through several geological and hydrological processes. Geothermal resources commonly have three components: 1) a heat source, 2) relatively high permeability reservoir rock, and 3) water to transfer the heat. In general, the heat source for most of the high-temperature resources (>150°C [300°F]) appears to be a molten or recently solidified intrusion, whereas many of the low-temperature (<100°C [212°F]) and moderate-temperature (between 100° and 150°C [212° and 300°F]) resources seem to result from deep circulation of meteoric water with heating due to the normal increase in temperature with depth. A number of high-temperature resources also occur in the Basin-and-Range province of the western U.S. as the result of deep circulation along major faults in a region of high heat flow. In most geothermal systems, fracture permeability controls water movement, but inter-granular permeability is also important in some systems. Water is, of course, the ideal heat transfer fluid because it has a high heat capacity and high heat of vaporization, and can therefore transport more heat per unit volume that any other common fluid.

Table 1 summarizes the way that geothermal resources are commonly classified. For the most part, only convective hydrothermal resources have been commercially developed. The other resource types will require new technology and/or higher energy prices in order to be more economically viable.

White and others (1971) and Henley and Ellis (1983) have discussed models for high-temperature convective hydrothermal systems. A body of molten, or recently solidified, hot (300°C to

1,200°C [570°F to 2,200°F]) rock presumably underlies higher-temperature hydrothermal resources. Interaction of this hot rock with ground water causes heating of the ground water, which then rises by buoyancy. The bulk of the fluid in hydrothermal systems is derived from meteoric water, with the exception of those few systems where the fluids are derived from seawater or connate brines (Craig, 1963). A free convective circulating system is set up with the heated water ascending in the center of the system along zones of permeability, spreading outward in the shallow subsurface or discharging to the surface, and with cool water descending along the margins and recharging the system. Rapid convection produces nearly uniform temperatures over large volumes of the reservoir. The temperatures and pressures generally lie near the curve of boiling point versus depth for saline water, and sporadic boiling may occur. Whether or not steam actually exists in a hydrothermal resource depends, among other less important variables, on temperature and pressure conditions at depth. Escape of hot fluids at the surface is often minimized by a near-surface, sealed zone or cap-rock formed by precipitation from the geothermal fluids of minerals in fractures and pore spaces (Wright and others, 1990).

Geothermal Resources in the U.S.

Most of the known hydrothermal resources and all of the presently known sites that are capable of electric power generation are in the western half of the U.S. (including Alaska and Hawaii) (figure 1). The majority of thermal springs and other surface manifestations of underlying geothermal resources are also in the west. Large areas underlain by warm waters in sedimentary rocks exist in Montana, North and South Dakota and Wyoming (Madison Group aquifers), but the extent and potential of these resources is poorly understood. Another important large area, much of which is underlain by low-temperature resources, is the north, northeast-trending Balcones-Ouachita structural belt in central Texas. The geopressured resource areas of the Gulf Coast and surrounding states are also shown. Resource areas indicated in the eastern states are speculative because little drilling has taken place to confirm their existence. Low- and intermediate-temperature resources are much more plentiful than are high-temperature resources. There are many thermal springs and wells that have water at temperatures only slightly above mean annual air temperature, the temperature of most non-geothermal shallow ground water (Wright and others, 1990).

Geothermal Use in the U.S.

Nearly all commercial geothermal exploration efforts in the U.S. in the past have been directed at finding high-temperature hydrothermal systems over 200°C (392°F) for the commercial generation of electricity. Current U.S. geothermal electric power generation totals approximately 6.94×10^{16} J/yr (2,200 MW), or about the same as four large coal-fired or nuclear power plants. U.S. geothermal power units are located in California, Nevada, Utah, and Hawaii. In recent years, more low- and moderate-temperature systems have been explored for space heating applications in buildings and greenhouses, and for electricity generation using modular, binary power plants. Uses for low and moderate temperature resources can be divided mainly into two categories: direct use and ground-source heat pumps. Moderate-temperature resources, under favorable circumstances, can be used to generate electricity using binary technology.

Direct use, as the name implies, involves using the heat in the water directly (without a heat pump or power plant) for such things as heating of buildings, industrial processes, greenhouses, aquaculture (growing of fish) and resorts. Direct-use projects generally use resource temperatures between 40°C to 150°C (104°F to 302°F). Current U.S. installed capacity of direct-use systems totals 1.48×10^{16} J/yr (470 MW) or enough to heat 40,000 average-sized houses.

Ground-source heat pumps use the earth or groundwater as a heat source in winter and a heat sink in summer. Using resource temperatures of 4°C (40°F) to 38°C (100°F), the heat pump, a device, which moves heat from one place to another, transfers heat from the soil to the house in winter and from the house to the soil in summer. Accurate data is not available on the current number of these systems; however, the rate of installation is thought to be between 10,000 and 40,000 per year (Oregon Institute of Technology, Geo-Heat Center, webpage: http://geoheat.oit.edu/whatgeo.htm, February 2000).

TERRESTRIAL HEAT FLOW IN UTAH

The worldwide average conductive heat flow to the earth's surface is about 61 milliwatts per square meter (mW/m^2) for the continents (Williams and Von Herzen, 1974). Considerable variation in heat flow exists in Utah. The area of highest heat flow in Utah is the Basin and Range province, which has typical values in the range 80 to 120 mW/m^2. The Colorado Plateau and the Middle Rocky Mountains provinces in Utah have heat-flow values near the average for the earth's surface (Sass and others, 1976; Sass and Munroe, 1974).

Andrew J. Henrikson and David S. Chapman of the University of Utah Department of Geology and Geophysics compiled and summarized heat-flow data in Utah using bottom-hole temperatures from oil and gas wells and from geothermal exploratory drill holes. The results of their work are presented in digital format as a companion to this report. To view the heat-flow report by Henrikson, and Chapman refer to (Terrestrial Heat-Flow in Utah) included as an Adobe Acrobat (pdf) document on this compact disk.

GEOLOGIC SETTING

Physiographic Regions of Utah

Utah comprises parts of three major physiographic provinces (Fenneman, 1931), each with characteristic landforms and geology. These include the Basin and Range Province, the Middle Rocky Mountains Province, and the Colorado Plateau Province. An overlapping of two of these provinces essentially forms a fourth distinctive physiographic region. The Basin and Range-Colorado Plateau Transition Zone extends through central and southwestern Utah, and contains physiographic and geologic features similar to both the Basin and Range and Colorado Plateau Provinces. The physiographic regions of Utah are shown on figure 2 and are included as a separate layer in the associated GIS coverages.

The Middle Rocky Mountains Province in northeastern Utah consists of mountainous terrain, stream valleys, and alluvial basins. It includes the north-south trending Wasatch Range, comprising mainly pre-Cenozoic sedimentary and Cenozoic silicic plutonic rocks, and the east-west trending Uinta Mountains, comprising mainly Precambrian sedimentary and metamorphic rocks.

The Colorado Plateau is a broad area of regional uplift in southeastern and south-central Utah characterized by essentially flat-lying, Mesozoic and Paleozoic sedimentary rocks. Scattered Tertiary and Quaternary volcanic rocks are present on the western margin of the Colorado Plateau in south-central Utah, and some Tertiary intrusive bodies are present in southeastern Utah. Plateaus, buttes, mesas, and deeply incised canyons exposing flat-lying or gently warped strata distinguish the Colorado Plateau of southeastern Utah. Bedrock units are spectacularly exposed, while surficial deposits are sparse.

The Basin and Range Province is noted for numerous north-south oriented, fault-tilted mountain ranges separated by intervening, broad, sediment filled basins. The mountain ranges are typically 20 to 50 km (12 to 31 mi) apart, 45 to 80 km (28 to 50 mi) long and are bounded on one, or sometimes two sides by high-angle, often listric, normal faults. Typical ranges are asymmetric in cross section, having a steep slope on one side and a gentle slope on the other. The steep slope reflects an erosion-modified fault scarp and the range is a tilted fault block (Hintze, 1988). Rocks within the Basin and Range vary widely in age and composition. Older rocks consist mostly of a variety of Mesozoic and Paleozoic sedimentary units and their metamorphic equivalents. Proterozoic-age rocks have limited exposures in the region. Cenozoic volcanic rocks and valley-fill units generally overlie the sedimentary and metamorphic rocks. Valley-fill deposits consist mostly of late Cenozoic lakebeds and alluvium as much as 3,000 m (10,000 ft) thick.

The Transition Zone is a broad region in central Utah containing structural and stratigraphic characteristics of both the Basin and Range province to the west and the Colorado Plateau province to the east. The boundaries of the Zone are the subject of some disagreement, resulting in various interpretations using different criteria (Stokes, 1988). Essentially, extensional tectonics of the Basin and Range has been superimposed upon the adjacent coeval uplifted blocks of the Colorado Plateau and Middle Rocky Mountains. The result is that block faulting, the principal feature of the Basin and Range, extends tens of kilometers into the adjacent provinces forming a 100-km- (62-mi-) wide zone of transitional tectonics, structure, and physiography (Hecker, 1993).

Late Cenozoic Tectonics in Utah

Comprising essentially the western half of Utah, the Basin and Range province is separated from the Middle Rocky Mountains by the Wasatch fault zone, and from the Colorado Plateau by the Transition Zone (figure 2). Within the Basin and Range and the Transition Zone, east-west structural extension is thought to have taken place over the past 17 million years (Hintze, 1988) creating numerous north-south-oriented, fault-bounded blocks. Prior to Basin and Range extension (during mid-Cenozoic time), voluminous silicic volcanism with associated hydrothermal activity took place within several east-west trending belts (Stewart and others, 1977). Patterns of volcanism changed during the latter stages of Basin and Range development to less-voluminous basalt and rhyolite (bimodal assemblage), spatially controlled by north-south Basin-and-Range faults.

Quaternary Faults

Hecker (1993) presents a detailed review of the Quaternary tectonic activity in Utah and describes the potential for earthquake-related hazards in the state. Utah is in a tectonically active region where the Intermountain seismic belt (ISB), a north-trending zone of historical seismicity, bisects the state (figure 3). The ISB coincides with the broad transitional eastern margin (including the Transition Zone) of the Basin and Range Physiographic Province, extending from southern Nevada, through Utah, southeastern Idaho, western Wyoming, and into central Montana. It includes the major active faults of Utah, such as the Wasatch fault system in northern Utah, and the Hurricane and Sevier faults in southern Utah and northern Arizona. Hecker's work on the Quaternary tectonics of Utah is briefly summarized in the following paragraphs. Mapped Quaternary faults in Utah are included with Hecker's fault database as a separate layer in our associated GIS coverages. The reader should refer to Hecker (1993) for a complete description of this information. Table 2 lists Hecker's Quaternary fault data-fields and descriptions of the values reported in the database.

The Wasatch Front region includes Quaternary tectonic features within a 200-km- (125-mi-) wide zone in northern Utah, centered on the Wasatch fault. The Wasatch fault zone, a normal fault with predominantly vertical movement, is the longest (340 km [210 mi]) and most tectonically active structure in Utah, with abundant evidence of surface-rupturing events during the Holocene. More than two-dozen other faults in the Wasatch Front region show evidence of one or more latest Pleistocene to Holocene surface-rupturing events.

In west-central Utah, latest Pleistocene to Holocene faulting events have been distributed across a series of fault zones spanning about 50 km (30 mi) wide. Based upon the extent and style of this faulting, the west-central Utah source region may extend eastward from Gunnison Lake near Manti to the Joes Valley area near the Emery-Sanpete County line B all eastward from the southern part of the Wasatch fault zone (figure 3).

Quaternary tectonism has been largely absent from eastern Utah, which includes the Uinta Mountains portion of the Middle Rocky Mountains and much of the interior of the Colorado Plateau. In the Paradox Basin, however, late Tertiary to Quaternary dissolution and collapse of large salt anticlines and salt flowage has continued locally into the late Quaternary, creating series of northwest-southeast-aligned fault structures (figure 2). Eastern Utah, like most of the Colorado Plateau, may lie east of the significant extensional forces of the Basin and Range, or may be underlain by more coherent crust.

In southwestern Utah, the Hurricane, Sevier, and Paunsaugunt faults are the dominant Quaternary structural features in the region. The Hurricane fault and its northward continuation, the Cedar City-Parowan monocline and the Paragonah fault, are considered by some workers to represent the boundary between the Basin and Range and Colorado Plateau provinces. Others place this system within the Transition Zone. The Sevier fault lies roughly 50 to 65 km (30 to 40 mi) eastward and subparallel to the Hurricane fault. These two features, along with the smaller Washington and Gunlock faults to the west, are considered by some to be the southern equivalent of the Wasatch Front zone of extension. Whereas long-term slip rates throughout the late Quaternary appear comparable between the two structurally aligned zones, slip rates during the Holocene are markedly different. The Wasatch Front region has experienced a considerable increase in surface faulting during the Holocene, particularly along the central Wasatch fault zone, where slip rates have reportedly increased by a factor of ten over longer term (late Quaternary) rates. In contrast, evidence of surface faulting along the Hurricane and Sevier faults during the Holocene in southwestern Utah is sparse.

Tectonically active regions typically have abundant active geothermal systems as fault movement fractures bedrock, thereby opening potential fluid pathways. In areas of active tectonism, meteoric water has more opportunity to circulate deep and absorb thermal energy from the surrounding rocks.

Quaternary Volcanic Rocks

Recent igneous activity may provide local, high-level, heat sources for geothermal systems. As a result, the distribution and timing of volcanic events is important for assessing the geothermal potential of a region. Hecker (1993) summarizes previous work (Best and others, 1980; Hoover, 1974; Clark, 1977; Lipman and others, 1978; Nash, 1986; Anderson, 1988; and Anderson and Christenson, 1989) to describe the distribution and timing of Quaternary volcanic rocks in Utah. The mapped distribution of Quaternary volcanic rocks is included with Hecker's database as a separate layer in our associated GIS coverages. The reader should refer to Hecker (1993) for a complete description of this information. Table 3 lists Hecker's Quaternary volcanic flows and vents data-fields and provides descriptions of the values reported in the two databases.

Clusters of young volcanic rocks (generally less than 2 Ma) extend from northwestern Arizona through southwestern and west-central Utah. These units consist of a bimodal assemblage of mainly basaltic rocks and less voluminous rhyolitic rocks. In southwestern Utah, several clusters of mostly basaltic rocks are oriented northeast-southwest, subparallel to the Basin and Range-Transition Zone margin. This package of volcanic rocks consists of series of basaltic flows and vents that do not seem to coincide with mapped faults. Rather, some vents lie adjacent to major faults, such as the Hurricane and Sevier faults, localized on the footwall or hanging-wall block, but not appearing to have used the fault as a conduit for magma. Cinder cones and mounds, which generally form alignments parallel to the faults, appear to have formed along steep joints.

In west-central Utah, another cluster of young basaltic rocks, with lesser quantities of rhyolite form a narrow belt generally aligned with the eastern margin of the Basin and Range. This volcanic assemblage formed in an intra-graben area between the Pavant and Tushar Mountains on the east, and the Mineral and Cricket Mountains to the west. The region is referred to as (from south to north) the northern part of the Escalante Desert, the Black Rock Desert, and the southern part of the Sevier Desert (figures 3 and 6). Volcanism here appears to have been concurrent with east-west extension across numerous, small-scale intra-basin faults. Vents and cinder cones mostly lie along high-angle normal faults, suggesting that the faults provided the conduits for movement of magma. Basaltic eruptions began in this region about 2 Ma and have continued intermittently since then. The latest eruptions include those during Lake Bonneville time at Pavant Butte (~15.3 ka) and Tabernacle Hill (~14.5 ka), and the youngest eruption in Utah at Ice Springs (~0.66 ka). This group of volcanic rocks, located in the Black Rock Desert of Millard County, also includes White Mountain, dated at about 400 ka years ago, making the flow the youngest exposure of rhyolite in Utah. A grouping of high-silica rhyolite flows and domes situated along the crest and western flank of the Mineral Mountains in Beaver County were erupted between about 800 and 500 ka; the same time interval that included basaltic eruptions to the northeast near Cove Fort.

A small volcanic field of Pleistocene age is located just north of the Great Salt Lake in the southern Curlew Valley in Box Elder County (figure 3). Basaltic rocks comprise the field and have been dated between about 0.7 and 1.15 Ma. Although the field is aligned generally parallel to basin-and-range faults, it does not appear to be spatially associated with any mapped Quaternary faults.

GEOTHERMAL RESOURCES IN UTAH

Previous Workers

The earliest implied reference to geothermal systems in Utah is by Gilbert (1890), who described Fumarole Butte and the nearby Crater (Abraham) Hot Springs. Stearns and others (1937) and Waring (1965) summarized data for about 60 known thermal occurrences. Mundorff (1970) prepared a comprehensive report on the thermal springs of Utah that included data on individual springs. Swanberg (1974) made estimates of subsurface temperatures using chemical analyses of water samples and employing "geothermometry." The technique called geothermometry is based on chemical equilibria and involves the use of water compositions (from springs or water wells) in mathematical formulas to estimate geothermal reservoir temperatures. Goode (1978) and Rush (1983) both produced summaries of geothermal occurrences in Utah. Goode's data compilation is particularly complete, whereas Rush's geologic descriptions are especially useful. In addition to these references, various authors from the University of Utah Department of Geology and Geophysics, Utah Geological Survey (formerly Utah Geological and Mineral Survey), Utah Office of Energy and Resource Planning (formerly Utah Energy Office), and the University of Utah Energy and Geoscience Institute (formerly University of Utah Research Institute) have published details on geothermal systems and geothermal applications in Utah.

Budding and Bugden (1986) compiled a bibliography of this early work up through the mid-1980s. Since then, several authors (Blackett, 1994; Blackett and Moore, 1994; Blackett and Ross, 1992;) have published more recent compilations and research on geothermal systems in Utah. Mabey and Budding (1987, 1994) compiled detailed geological, geochemical, and geophysical information, including previously unpublished data on seven individual systems within the "Sevier thermal area," an area of central and southwestern Utah containing all of Utah's known high-temperature geothermal systems (figure 5). Budding and Sommer (1986) gathered field data and published a study of low-temperature geothermal resources in the St. George area of southwestern Utah. Wright and others (1990) summarized geothermal resources and developments in Utah up through the 1980s, and discussed how factors such as regional low energy costs resulted in relative low growth of geothermal energy in the state. Blackett and Ross (1992) published the results of geochemical and geophysical studies for geothermal systems within the Escalante Desert of southwestern Utah. Several authors in Blackett and Moore (1994) presented geological summaries and development histories of the state's principal geothermal areas. Blackett (1994) prepared an inventory of thermal wells and springs in Utah as part of a U.S. Department of Energy program to update the geothermal database for all of the western states. We have updated the annotated geothermal bibliography compiled by Budding and Bugden (1986) to include publications related to geothermal studies in Utah from 1987 to 2000, and included it as a separate document on this CD-ROM.

Geothermal Occurrences in Utah

With few exceptions, the higher temperature geothermal areas in Utah occur either in the Basin and Range province or within the Transition Zone (figure 4). In central and western Utah, most thermal areas are located in valleys near the margins of mountain blocks, and are probably controlled by active Basin and Range faults. Other geothermal systems occur in hydrologic discharge zones at the bottoms of valleys. A few thermal areas are situated in mountainous regions.

The most significant known occurrence of geothermal water in eastern Utah is from oil wells of the Ashley Valley oil field, which yield large volumes of nearly fresh water at temperatures between 43°C and 55°C (109°F and 131°F) as a byproduct of oil production. In 1981, the Ashley Valley field yielded 5.42 million m^3 (26.1 million barrels) of water (Goode, 1985).

Using geothermometry and other information, Rush (1983) suggested that six areas in Utah are probably high-temperature geothermal systems with reservoir temperatures above 150°C (302°F). He also suggested that ten other areas could be classified as moderate-temperature geothermal systems with reservoir temperatures between 100°C and 150°C (212°F and 302°F). Known high-temperature systems include the Roosevelt Hot Springs and Cove Fort - Sulphurdale Known Geothermal Resource Areas (KGRA). KGRA is a federal classification pertaining to geothermal areas where federal lands have competing leasing interests. Other potential high-temperature systems are Thermo Hot Springs, Joseph Hot Springs, the Newcastle area, and the Monroe-Red Hill area. Mabey and Budding (1987) compiled detailed information on all of Utah's moderate- to high-temperature geothermal systems and proposed the name "Sevier thermal area" to encompass the region in southwestern Utah in and around the Sevier, Black Rock, and Escalante Deserts (figure 5) where a number of geothermal systems have estimated reservoir temperatures greater than 100°C (212°F).

Geothermal Use in Utah

Presently, electric power is generated at the Roosevelt Hot Springs and the Cove Fort -

Sulphurdale KGRAs. The installed gross capacity for the two areas is about 33 MW (electric). Commercial greenhouses, that use thermal water for space heating, operate at Newcastle in Iron County, and at Crystal Hot Springs near Bluffdale in Salt Lake County. Ten resorts use geothermal water for the heating of swimming pools, small space-heating applications, and therapeutic baths. Two of the newer direct-use geothermal developments consist of commercial SCUBA-diving and aquaculture facilities near Grantsville in Tooele County, and near Plymouth in Box Elder County.

Power Plants

Utah Power, a PacifiCorp company that merged with Scottish Power in 1999, has operated the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area near Milford in Beaver County since 1984. Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from wells that tap a geothermal resource in fractured, crystalline rock. The resource depths range generally between 640 and 1,830 m (2,100 and 6,000 ft). Resource temperatures are typically between 271 and 316°C (520 and 600°F). Wellhead separators are used to "flash" the geothermal fluid into liquid and vapor phases. The liquid phase, or geothermal brine, is channeled back into the reservoir through gravity-fed injection wells. The vapor phase, or steam fraction, is collected from the production wells and directed into the power plant at temperatures between 177 and 204°C (350 and 400°F) with steam pressure approaching 7.66 kilograms per square centimeter (109 psi). The plant produces 26 MW gross (23 MW net), which equals the energy that would be produced by burning roughly 48,000 cubic meters (300,000 barrels) of oil annually.

At Sulphurdale in Beaver County in 1985, Mother Earth Industries, in cooperation with the City of Provo, installed a geothermal binary-cycle power system and a steam-turbine generator. In 1990, Provo City and the Utah Municipal Power Agency, the current field operator, dedicated the Bonnett geothermal power plant, which became the third geothermal power facility to go on-line at Sulphurdale to provide electricity for Provo City. The estimated net output capacity from the power units is about 10 MW. Because hydrogen sulfide (H_2S) gas is produced, the plant includes a sulfur abatement system designed to extract up to 1.36 metric tons (1.5 short tons) per day of sulfur. Production wells primarily tap a shallow, vapor-dominated part of the geothermal system at depths between 335 and 366 m (1,100 and 1,200 ft). A deeper well, however, reportedly taps the liquid-dominated part of the system. Spent fluid is returned to the reservoir through a deep injection well.

Commercial Greenhouses

Various research organizations and energy companies became interested in the Newcastle area of Iron County in the 1970s after farmers accidentally discovered a relatively shallow hydrothermal system while drilling an irrigation well. The well had encountered a hot-water aquifer with a maximum temperature of 108°C (226°F) between depths of 75 and 94 m (245 and 310 ft). Subsequent studies by the UGS suggest a model of hot water rising along a range-bounding fault and discharging into an aquifer in unconsolidated Quaternary sediments, forming a broad outflow plume. Temperatures within the outflow plume generally range between 82° and 104°C (180° and 220°F). Several commercial greenhouses, covering about 100,000 m^2 (25 acres), use the geothermal fluid from shallow production wells (152 m [~ 500 ft] deep) to produce high-quality flowers, vegetables, and ornamental plants year-round.

Crystal (Bluffdale) Hot Springs is located at the southern end of the Salt Lake Valley where Bluffdale Flower Growers (formerly Utah Roses) operates a geothermal-heated greenhouse complex. The facility covers about 11,700 m^2 (2.9 acres), and produces cut roses as its primary product. Utah Correctional Industries at the nearby Utah State Prison uses thermal water from a well for raising tropical fish commercially. Surface spring temperatures are about 62°C (144°F). Subsurface temperatures of 88°C (190°F) have been reported in one of two 122-m- (400-ft-) deep production wells. The springs normally issue from valley alluvium into several ponds. When production wells are in operation, the surface springs and ponds reportedly dry up.

Therapeutic Baths, Resorts, and Aquaculture

Bonneville SeaBase is a SCUBA-diving facility developed at Grantsville Warm Springs located about 66 km (40 mi) west of Salt Lake City along Interstate Highway 80 in Tooele County. SeaBase consists of several dive pools fed by warm springs and stocked with tropical marine fish. The facility is associated with Neptune Divers of Salt Lake City, a business devoted to SCUBA diving and related-product sales.

At Belmont (Udy) Hot Springs in northeastern Box Elder County, about 50 hot springs and seeps issue along the Malad River at about 52°C (125°F). In addition to a golf course and camping facilities, the resort has therapeutic hot tubs, a swimming pool, and a SCUBA diving pool. The resort also operates a commercial aquaculture facility, raising lobsters and crayfish for distribution out of the local area.

Crystal (Madsen) Hot Springs Resort, near Honeyville along Interstate Highway15 in Box Elder County, uses cold springs and hot springs at the same facility. The springs are situated along the northern extension of the Wasatch fault, which traverses along the western side of the Wellsville Mountains. A cold spring (11°C [52°F]) is used to help fill a 1.1-million-liter- (300,000-gallon-) pool, while hot springs 60°C (140°F) fill therapeutic hot tubs, mineral pools, and also flow into the swimming pool. Pool temperatures range from 29° to 44°C (85° to 112°F).

Thermal springs in and around the community of Midway in Wasatch County issue from several widespread, coalescing travertine mounds covering an area of several square kilometers. Temperatures in the springs generally range from 35° to 46°C (95 to 115°F). Thermal water at Midway probably originates from deep circulation of meteoric water from recharge zones located to the north near Park City. The Mountain Spa Resort uses thermal water for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 35°C (95°F) thermal pool inside "the old hot pot," a large travertine mound.

The Monroe-Red Hill Hot Spring area is 16 km (10 mi) south of Richfield in Sevier County. The proprietors have named the resort "Mystic Hot Springs" and offer a geothermal-heated swimming pool, therapeutic baths, camping facilities, and tropical fish ponds. The Monroe and Red Hill Hot Springs issue at about 77°C (170°F) near the surface trace of the Sevier fault adjacent to the Sevier Plateau. The area was the focus of U.S. Department of Energy-sponsored geothermal studies in the late 1970s.

Veyo and Pah Tempe Hot Springs resorts in southwestern Utah offer swimming and therapeutic baths. At Veyo Hot Springs Resort, located southeast of the town of Veyo along the Santa Clara River canyon, spring flows are channeled to a swimming pool at a temperature of about 32°C (89°F). At the Pah Tempe Hot Springs Resort springs flow from a number of vents along the Virgin River at about 42°C (108°F) near where the river crosses the Hurricane fault between the towns of Hurricane and La Verkin. The thermal water is channeled into a swimming pool and therapeutic baths.

GEOTHERMAL WELL AND SPRING DATA FOR UTAH B UTAHGEO.dbf

Background

For more than two decades, the UGS has worked with other state and federal agencies to compile data sets and files on thermal wells and springs in Utah. The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE), compiled the first comprehensive database of geothermal wells and springs in Utah in support of two national geothermal assessments (Muffler, 1979; and Reed, 1983). The data for these assessments were incorporated into GEOTHERM (Bliss and Rapport, 1983), a mainframe computer system of databases and software used to store, locate, and evaluate information on geothermal systems. GEOTHERM received data until it was taken off-line in 1983. The USGS preserved these data and made them available for public use through a series of Open-File reports presenting information on source location, description, and water chemistry.

The UGS (formerly Utah Geological and Mineral Survey) helped with data compilation for GEOTHERM, and eventually published a state geothermal resource map in cooperation with DOE and the National Oceanic and Atmospheric Administration (Utah Geological and Mineral Survey, 1980). Based primarily on the work of Goode (1978), the map listed about 330 wells and springs included in GEOTHERM, showed heat-flow information from the work of Chapman and others (1978, 1981) and Sass and others (1976), and outlined areas of prospective value for geothermal exploration. Since the national geothermal assessments were completed in the early 1980's, no new resource data have been gathered at a regional scale. The map also showed nine Known Geothermal Resource Areas (KGRAs), a classification for federal leasing based on competitive interests and/or geologic criteria. Since 1980, only three of these areas (Cove Fort-Sulphurdale, Roosevelt Hot Springs, and Crater Springs) still maintain the classification of KGRA. The others (Meadow-Hatton, Monroe-Joseph, Thermo, Lund, Newcastle, and Navajo Lake) were declassified because of either a lack of competitive interests or, a lack of an indicated resource.

In 1991, the Geothermal Division of the U.S. Department of Energy (DOE) initiated the Low-Temperature Geothermal Resources and Technology Transfer Program, following a special appropriation by Congress, to encourage wider use of lower-temperature geothermal resources through direct-use, geothermal heat-pump, and binary-cycle power conversion technologies. The Oregon Institute of Technology (OIT), the University of Utah Research Institute (now the Energy and Geoscience Institute), and the Idaho Water Resources Research Institute organized the federally-funded program and enlisted the help of geothermal specialists in ten western states to re-inventory thermal wells and springs, and compiled relevant information on each source. As part of this project, the UGS compiled a database with information on thermal wells and springs in Utah with temperatures of 20°C (68°F) or greater (Blackett, 1994). The database contained 964 records on 792 locations of wells and springs, and it included the location of the well or spring, its temperature, depth, flow-rate, and chemical constituents. The database was developed for use on personal computers to provide users with access to specific geothermal information in Utah. Resource maps of thermal wells and springs, derived from the database, were included in the 1994 open-file report.

Sources of Data

Because the data contained in the 1994 UGS open-file report (Blackett, 1994) pertained mostly to low-temperature geothermal sources, information on deep, exploratory geothermal wells was generally not included. Published data on deep, geothermal exploration wells is included with this report. In addition, an effort was made to include new information generated from the drilling of new wells, or additional data on existing wells that has become available since that time.

Like the 1994 open-file report, well and spring information included here was obtained from the published sources listed in the references, and from the U.S. Geological Survey/Water Resources Division (USGS/WRD). The Utah district office of the USGS/WRD provided location, descriptive, and water-chemistry data on wells and springs in Utah, with measured temperatures of 18°C (64°F) or greater, from the National Water Information System (NWIS) database.

These data were then culled using a cutoff temperature. The general criteria used to determine a cutoff temperature was if a ground-water source surface temperature is greater than 10°C (18°F) above the mean annual ambient temperature, then it is considered "thermal." Ground-water sources with temperatures below the cutoff temperature are not considered thermal and, therefore, are not included. Mean annual ambient temperatures (MAAT) were estimated for all counties using information provided in Greer and others (1981). In general, because the MAAT for most of Utah is near 10°C (50°F), a measured temperature of 20°C (68°F) was used to define the cutoff temperature of thermal sources for most counties. In the case of some of the northern counties, or those at higher elevations, a lower cutoff temperature was used to compensate for a lower MAAT. Table 4 lists the cutoff temperatures used for each county. Since no thermal sources were recorded in Rich and Daggett Counties, they do not appear on the list. In addition, it should be noted that a 20°C (68°F) cutoff was still used in those counties with relatively higher MAATs, in particular Washington County (MAAT = 16°C [61°F]). This was done for consistency with the previous, 1994 assessment.

UTAHGEO Database Format

Thermal well and spring data listed in Appendices A and B and included in the GIS coverage differs somewhat from the previous, 1994 open-file report (Blackett, 1994). The "UTAHGEO" GIS coverage and associated database file contains 2,985 records pertaining to 1,133 sources of "thermal" water in Utah. In nearly all cases, these sources are either springs or water wells; these data are recorded in the "TYPE" field. Sources are coded as oil-field drain (D), mine (M), or a well collector (C) in fewer than ten cases.

Table 5 lists the field name, field contents, and measurement units for the 38 data fields contained in "UTAHGEO.dbf." The information within "UTAHGEO" is organized into two broad categories B *Descriptive Data* and *Fluid-Chemistry Data.* The *Descriptive Data*, listed in Appendix A, presents the location and physical parameters of the source. Included in this category are the GIS-map designation for the source (county code plus number), location of the source in three coordinate systems (latitude-longitude, UTM, and cadastral), physical parameters (temperature, depth of well, and flow-rate), date of measurement, and a short reference citation. The short citation refers to the attached reference list. The *Fluid-Chemistry Data*, listed in Appendix B, presents quantitative chemical analyses of fluid samples from the source, including major cations and anions, pH, conductivity, and total dissolved solids (TDS). Table 6 provides a key to county codes shown as part of the MAPNAME data field.

Limitations of UTAHGEO Database

Data from the 1994 open-file report (Blackett, 1994) were combined with data from the USGS's NWIS to create UTAHGEO. Since many of the records in the 1994 database used information taken from an older USGS database similar to the NWIS, UTAHGEO includes many duplicate records. There are enough subtle differences, however, between the new data and the previous, 1994 data set that we decided to keep both sets of information in the UTAHGEO database. The reader is urged to research records with their referenced source if more detailed information is required, or if the data need verification.

At a minimum, locations, types, temperatures, and references are reported. Many cells within other fields of the database, however, are empty because data were often not available for a particular parameter.

An effort was made to correct more obvious location errors for well-known geothermal sources in Utah. In a number of instances, plotted locations of sources did not obviously conform to the reported cadastral location (well and spring numbering system for Utah). In most cases, further research revealed that the reported cadastral location was correct and the coordinate location was not. In any case, the reader should be aware of location inconsistencies and be prepared to do more research on individual sources as needed.

More information is available on individual sources from the USGS/WRD and the Utah Department of Natural Resources, Division of Water Rights. The USGS/WRD's office in Salt Lake City provides information on ground-water sources in Utah as well as other water-related information.

The address for the USGS/WRD's Internet site is: http://ut.water.usgs.gov/. In addition to providing information regarding water usage and water right ownership, the Division of Water Rights also provides information on individual wells and springs in the state. The Division maintains an Internet website at: http://nrwrt1.nr.state.ut.us/.

Well and Spring Numbering System in Utah

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government (figure 6). The number designates a location and describes its position in the land net. The land-survey system divides the state into four quadrants with respect to the Salt Lake Base Line and Meridian (origin in Salt Lake City), and these quadrants are designated by uppercase letters as follows: A-northeast, B-northwest; C-southwest; and D-southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by the three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section (generally 0.04 km^2 or 10 acres). The quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast. For example, the well/spring number "(C-36-15)20bca" describes a location in T.36S., R.15W., in the northeast quarter of the southwest quarter of the northwest quarter of Section 20. The Uinta Special Meridian is a separate land-survey system established for the Uinta Basin in northeastern Utah. Wells and springs located using this system are designated by a preceding "U," for example "U(B-01-08)30ddb." Within the UTAHGEO database, the well/spring number for each record is included under the fieldname "LOCATION."

GEOTHERMAL RESOURCE AREA SUMMARIES

Wasatch and Uinta Mountains

Regional Setting

Comprising the Middle Rocky Mountains Physiographic Province in Utah (figure 2), the Wasatch and Uinta Mountains lie near the boundaries with the Basin and Range Province and the Colorado Plateau Province, respectively. These mountain ranges stand high above the surrounding terrain and are composed of relatively old rock formations that have been subjected to faulting and folding from several, major orogenic events. During the process of deformation, the rock units were faulted, fractured, and folded by tectonic activity, and intruded by igneous masses, thereby creating permeable conduits for fluid movement. These conduits, coupled with abundant recharge mostly from snow-melt, provide the conditions for meteoric water to percolate deep, become heated by the Earth's natural heat, rise through forced convection, and surface at points of low pressure in this "convective hydrothermal" system. Often, thermal waters will mix with shallow meteoric waters, becoming diluted before issuing at the surface or discharging into shallow aquifers. Much of the recharge water in the Wasatch Range eventually reaches systems at the eastern edge of the Basin and Range Province, but a considerable amount of thermal water discharges to springs and aquifers along the eastern slope or the Wasatch Hinterlands (described by Stokes, 1988). Such thermal waters are manifested in high mountain valleys like Cache Valley or Heber Valley (Midway area), or as high-altitude, point-source occurrences like those in Third Water Canyon and at Split Mountain.

Cache Valley

Cache Valley is a narrow, north-trending valley in northern Utah and southern Idaho, which lies on the northeastern edge of the Great Basin (figure 7). The overall structure of the valley is a graben bounded by high-angle normal faults. The structural basin forming Cache Valley is filled by as much as 1.6 km (1 mi) of semi-consolidated and unconsolidated Tertiary and Quaternary strata. De Vries (1982) analyzed the geothermal resource potential of Cache Valley and reported temperature, water chemistry, and thermal-gradient data. For the evaluation, she compiled temperatures and water chemistries from 90 wells, and gathered temperature-depth profiles from 12 wells. The results of her investigation suggest that three areas within the Cache Valley contain anomalously warm water. Geochemical indicators suggest that reservoir temperatures are between 50° and 100°C (122° and 212°F). Chemical mixing models applied to the same analyses indicate that reservoir temperatures may approach 200°C (392°F) (de Vries, 1982).

In the North Logan area, well temperatures ranged up to 25.1°C (77.2°F), although a bottom-hole-temperature of 32.5°C (90.5°F) was recorded in one of the thermal gradient holes (CVG-9). De Vries (1982) suggests that the occurrence of thermal waters is due to increased vertical permeability along an intersection of two segments of the nearby East Cache Valley fault zone. Estimated resource temperatures near North Logan range up to 56.1°C (133.0°F).

Around Benson, de Vries measured well temperatures that ranged up to 23°C (73°F). Geothermometry of water chemistry was ambiguous. De Vries suggests that the thermal water near Benson may have some relationship to the Clarkston fault zone to the west.

Three springs and one well in the Trenton area have temperatures ranging from 22.9° to 50.1°C (73.2° to 122.2°F). Tufa deposits are reportedly associated with the Dayton fault zone in this location. De Vries reports that Cottle's spring had a sulfurous odor and a temperature of 22.9°C (73.2°F). A tufa mound surrounds Gancheff's spring and the spring water has a fairly constant temperature at about 30°C (86°F). Gancheff's spring water has a dissolved solids content of about 4,500 mg/L (note: for dilute solutions, mg/L is essentially equivalent to parts-per-million [ppm]). The highest temperature recorded near Trenton was in an exploratory gas well (Karmis-Brown) where de Vries measured a temperature of 50.1°C. The Karmis-Brown well was drilled to a depth of 1,587 m (5,207 ft).

Midway Area

Midway is a small farming and resort town located about 8 km (5 mi) west of Heber City in Wasatch County. Thermal springs in and around the community issue from several widespread, coalescing travertine mounds covering an area of several square kilometers (Baker, 1968). Temperatures in these springs range from 38°C to 46°C (100°F to 115°F). Kohler (1979) suggested that thermal water at Midway originates from deep circulation of meteoric water from recharge zones located to the north near Park City. Thermal water is contained within fractured, Paleozoic quartzite in a broad antiform structure. Leakage to the surface is expressed as scattered thermal springs and widespread travertine deposits. Chemical geothermometry indicates that the maximum reservoir temperature is about 75°C (167°F).

Thermal water here has been used in pools and spas for several decades. Some new residences in this rapidly growing area reportedly use the geothermal water for space heating. A DOE-funded study (Kohler, 1979) showed that the geothermal system extends for several square kilometers around Midway. Midway's population was 1,554 during the 1990 Census, an increase of 30 percent over the 1980 Census. U.S. Highways 189 and 40 connect Midway with the larger, nearby communities of Provo, Heber, and Park City. The Heber Valley is an agricultural area producing alfalfa, corn, and cattle. At the Mountain Spa Resort, thermal water is used for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 35°C (95°F) thermal pool inside "the old hot pot," a large travertine mound (see section on geothermal uses).

Third Water Canyon

Third Water Hot Springs, well known to hikers and mountain-bikers, are located in eastern Utah County. They are unusual because they occur at an elevation of 1,890 m (6,200 ft) in the Wasatch Mountains. The springs were known only to recreational enthusiasts and were not reported in previous geothermal or water-resource publications. Third Water Hot Springs issue from multiple vents along Third Water Creek, about 5 km (3 mi) east of Three Forks Campground in Diamond Fork Canyon. Access to the springs is by hiking, mountain biking, or on horseback. The springs occur over a distance of about 0.5 km (0.3 mi) in and along the stream course, with many vents located below a 6 m (20 ft) waterfall. Abundant vertical fractures are apparent with some evidence of offset. Bedrock consists mostly of pebble and cobble conglomerate, probably of upper Cretaceous (Price River Formation) or lower Tertiary (North Horn Formation) age.

Spring temperatures range from tepid to a maximum of 55.5°C (131.9°F) at a vent located just below the waterfall. The springs give off a pervasive sulfurous odor, and deposit both white and black mineral coatings on the stream bottom. A pH of 7.03 was measured at the sampled vent, and analyses of a water sample yielded a TDS content of 932 mg/L. Geothermometry suggests equilibration temperatures between 65°C and 97°C (149°F and 207°F). Results of the laboratory analysis (included in the database) indicate a sodium bicarbonate, chloride, sulfate type water.

Castilla and Thistle Hot Springs

Klauk and Davis (1984) presented thermal and chemical data on Castilla Hot Springs (two springs) located about 13 km (8 mi) southeast of Spanish Fork in Spanish Fork Canyon, along the north side of U.S. Highway 6/89 in Utah County (figure 8). Temperature at both springs was 36°C (97°F).

They also presented data on another spring located about 5 km (3 mi) southeast of Castilla exposed in the bed of the Spanish Fork River near the massive Thistle earthflow. At the time of Klauk and Davis' (1984) study, the earthflow had dammed the Spanish Fork River, exposing the riverbed. They reported the temperature of this spring as 50°C (122°F). They also reported that small seeps, ranging in temperature from 7.2 to 26.7°C (45° to 80°F), were also noted in the streambed from Thistle Hot Spring to the confluence with Diamond Fork Creek, a distance of 2.7 km (1.7 mi). It is not known if Thistle Hot Spring or the other seeps are evident at present.

Diamond Fork

Diamond Fork Warm Springs are about 27 km (17 mi) east of Spanish Fork in Utah County in SE¼, section 14, T.8S., R.5 E (figure 8). The springs issue from Cretaceous conglomerate rocks along Diamond Fork, a tributary to the Spanish Fork River, at 20°C (68°F). TDS content is 837 mg/L, and there is a pervasive hydrogen sulfide odor associated with the springs. The water type is calcium-sodium-sulfate, and Mundorff (1970) reported a discharge range from 1,300 to 2,700 L/min (350 to 700 gpm).

Split Mountain Warm Springs and Duchesne River Springs

A few thermal springs issue from fault and fracture zones along the south flank of the Uinta Mountains. At Split Mountain Warm Springs (figure 4), within Dinosaur National Monument, water issues from fractured Mississippian-age rocks along the crest of the Split Mountain anticline at 30°C (86°F). Goode (1978) reported a flow of 10,200 L/min (2,700 gpm) and TDS of 942 mg/L at Split Mountain, and reported that the water issues from several spring orifices. Goode also described a group of warm springs in the Duchesne River valley near Hanna that flow about 8,517 L/min (2,250 gpm) of low-TDS water at a temperature of 26°C.

Uinta Basin

Regional Setting

The Uinta Basin in northeastern Utah is a broad, east-west trending basin that sub-parallels the Precambrian-cored Uinta Mountains to the north. It encompasses more than 26,000 square kilometers

(10,000 mi^2), most of northeastern Utah (figure 4). Structurally, it is a broad east-west asymmetrical syncline with a steep north limb and a gently dipping south limb. The basin is a Laramide orogenic feature, filled primarily with Tertiary alluvial, fluvial, and lacustrine deposits. A number of oil reservoirs occur in the basin as well as other hydrocarbon deposits (gilsonite, oil-shale, and bituminous sandstone). Several significant faults near the south flank of the Uinta Mountains run subparallel to the axis of the basin, and may act as conduits for vertical movement of thermal water.

Ashley Valley

In his detailed report on the thermal waters of Utah, Goode (1978) summarized geothermal occurrences in the Uinta Basin. Thermal water is produced as a byproduct of oil production within the Uinta Basin. At the Ashley Valley field, Goode reported that low-TDS water (1,500 mg/L) at temperatures between 43° and 55°C (109° and 131°F) was produced with oil, separated in settling ponds, and diverted into the local irrigation system. No attempt to use the heat in geothermal applications has been reported.

Wasatch Front Valleys

Regional Setting

Many thermal springs are present along the Wasatch Front, from Utah Valley on the south, to the state line on the north (figures 7 and 8). These systems are just west of the Wasatch Mountains at the eastern edge of the Basin and Range Physiographic Province and within the Intermountain seismic belt. The thermal springs are considered to be the result of deep circulation of meteoric water, heated by the normal geothermal gradient of the Basin and Range province.

The Wasatch Range rises abruptly from the valley floor. This steep mountain front follows the Wasatch Fault zone, where the fault zone has displaced rocks in the upthrown block of the Wasatch Range several tens of thousands of feet from rocks in the downthrown block. Rocks of the downthrown block are buried beneath several thousand feet of lakebed sediment and alluvium.

The Wasatch Front valleys lie immediately west of the Wasatch Range in north-central Utah within what Stokes (1988) refers to as the Wasatch Front Valley section of the Basin and Range physiographic province. Stokes (1988) describes the Wasatch Front as not one continuous open valley, but a number of spurs, or salients divided into distinct geographic segments. Utah Valley lies farthest south and includes Utah Lake. Utah Valley (upper Jordan Valley) is bounded on the north by the Traverse Mountains that separate it from Salt Lake Valley (lower Jordan Valley) to the north. The Salt Lake salient (Beck's spur) forms a partial barrier northeast of the Salt Lake Valley and separates it from the much longer and less well defined tract containing the communities of Bountiful, Centerville, Farmington, Kaysville, Layton, Clearfield, and Ogden. This tract has no distinct name, but here we'll refer to it as the Weber River delta district. North of Ogden another projection, the Pleasant View salient, extends from the Wasatch Range westward into the lowlands, providing a geographic and structural southern boundary to what may be called the lower Bear River Valley. The northernmost valley is referred to as the Malad River Valley, which extends into southern Idaho (Stokes, 1988).

Stokes (1988) subdivides the Wasatch Range into three segments. The northern segment extends from the Bear River narrows on the north to the Weber River on the south. The central segment extends from the Weber River to the American Fork River. The southern segment extends from the American Fork River southward to Salt Creek near Nephi. The northern and southern subdivisions consist mainly of Paleozoic rocks that have been moved eastward along large thrust sheet formed during the Cretaceous Sevier orogeny. Rocks of the central subdivision have remained largely in place, possibly buttressed by the Uinta Mountains massif during the Cretaceous period. The central subdivision also contains several large Tertiary intrusive stocks near Salt Lake City. The Wasatch Range is crosscut by numerous faults and folds, which predate the formation of the Wasatch Fault.

Wasatch Front Valleys - Lower Bear River Valley

The lower Bear River Valley includes the region extending from the Weber-Box Elder County line at the Pleasant View spur northward to the Utah-Idaho border. It includes the area west of the Wasatch and Wellsville Mountains and east of the West Hills, Blue Spring Hills, and Promontory Mountains. Thermal springs in the area were included in early geothermal studies by Mundorff (1970) and Goode (1978). The area was later the focus of State-Federal sponsored geothermal investigations (Murphy and Gwynn, 1979b; Klauk and Budding, 1984). Several of the better-known Utah thermal springs occur in this region including Crystal Hot Springs (Madsen) and Belmont (Udy) Hot Springs.

Utah Hot Springs

Utah Hot Springs issue from several orifices in valley fill at the western edge of the Pleasant View salient about 90 m (300 ft) west of U.S. 89 on the Box Elder-Weber county line. The area is located within a utility and transportation corridor where the discharge, in the past, was channeled to baths, pools, and greenhouses. A small commercial greenhouse presently uses the fluids for heating during winter months. Murphy and Gwynn (1979b) reported that the maximum temperature was 63°C (145°F), although temperatures reported from other studies made from 1843 to 1967 ranged between 57 and 58.5°C (135 and 137°F).

TDS content of Utah Hot Springs water ranges between 18,900 and 25,200 mg/L; 90 percent of the dissolved constituents are sodium and chloride ions. In addition to the high salinity, the water contains 3 to 5 mg/L dissolved iron that oxidizes and precipitates when the water is aerated. Felmlee and Cadigan (1978) reported that the water also contains measurable quantities of radium (66 µµg/L) and uranium (0.04 µg/L).

Crystal (Madsen) Hot Springs

Crystal (Madsens) Hot Springs, located about 2 km (1.3 mi) north of Honeyville in Box Elder

County (figure 7) flow from the base of a small salient extending west from the Wellsville Mountains (northern extension of the Wasatch fault zone). The springs flow from fractured Paleozoic rocks at temperatures between 49.5° and 57°C (121° and 135°F). Although there are a number of warm springs and seeps in the area, the original main spring orifice is no longer visible. A nearby cold spring 11°C (52°F), along with water from the hot springs, is used to help fill a 1.14-million-liter- (300,000-gallon-) pool, while the hot springs alone are used to fill therapeutic hot tubs and mineral pools. Swimming pool temperatures range from 29° to 44°C (85° to 112°F). Roughly 610 m (2,000 ft) south of the main spring, a series of low-flowing warm springs and seeps are present in a small branch of Salt Creek, a tributary of the Bear River (Murphy and Gwynn, 1979a).

Total flow from all springs and seeps at Crystal Hot Springs drains southwest along Salt Creek and has been estimated at about 15,300 L/min (4,000 gpm). Mundorff (1970) estimated discharge of about 6,370 L/min (1,680 gpm) for the main hot spring (Murphy and Gwynn, 1979b).

TDS content of the thermal waters at Crystal (Madsen) Hot Springs is the highest of any spring in Utah with TDS measured values above 46,000 mg/L. Over 90 percent of the ions in solution are sodium and chloride. In addition to high TDS values, the springs reportedly contain elevated levels of radium (220 µµg/L) and uranium (1.5 µg/L) (Felmlee and Cadigan, 1978).

Belmont (Udy) Hot Springs

Belmont Hot Springs (formerly referred to as "Udy Hot Springs") issue to the surface about 1.6 km (1 mi) southwest of Plymouth in northeastern Box Elder County (figure 7) on the floodplain of the Malad River. The springs consist of a number of orifices that form a roughly semicircular pattern on the western flank of the river. The springs flow from fractured Paleozoic limestone at a small escarpment between the flood plain and the higher terraces of the Malad River Valley. Water temperatures range from 34° to 43.5° C (93° to 110° F). A large lake containing several spring orifices is the most conspicuous feature of the springs, but a series of smaller orifices given names such as "Indian Pool," Morning Glory Hole," and "Mud Pots" are present south of the large lake. Water from all orifices drain directly into the Malad River. Development at the Belmont Hot Springs Resort has modified the original springs (Murphy and Gwynn, 1979b).

The Belmont Hot Springs system is situated between the Wasatch Range on the east and the West Hills to the west. The two ranges, different in terms of geology and structure, are separated by Basin and Range structures beneath the Malad River Valley (Murphy and Gwynn, 1979b).

Dissolved constituents, like many other Wasatch Front valley springs, are mainly sodium and chloride ions with TDS values approaching 8,400 mg/L.

In addition to a golf course and camping facilities, Belmont Hot Springs resort includes three therapeutic hot tubs, a swimming pool, SCUBA diving pools, and operates a commercial aquaculture facility to raise lobsters.

Little Mountain Warm Spring

Little Mountain Warm Spring, at the south end of Little Mountain in Box Elder County, has a water temperature of 32°C (90°F). Predominant ions present in the thermal water are bicarbonate, sodium, and chloride (Murphy and Gwynn, 1979b). Klauk and Budding (1984) suggest that Little Mountain Warm Spring and Stinking Hot Springs, located about 1.6 km (1 mi) to the southeast, may be related to the same fault system and, based on water chemistry, the same type of reservoir rocks.

Stinking Hot Springs

Stinking Hot Springs is located about 10 km (6 mi) southwest of Bear River City. The springs issue from faulted Mississippian limestone at the base of the south end of Little Mountain. The springs get their name from the presence of hydrogen sulfide gas in the vapors. Water temperatures are known to range between 39.5° and 51°C (103° and 124°F). Discharge from the spring ranges from 19 to 170 L/min (5 to 45 gpm). TDS content of the sodium chloride-type water ranges from 29,000 to 30,400 mg/L. Mundorff (1970) reported that lithium, bromide, and iodide concentrations are high. The high TDS content likely results from saline minerals within the aquifer (Klauk and Budding, 1984; Mundorff, 1970).

Bothwell (Salt Creek) Warm Springs

Bothwell Warm Springs, 32 km (20 mi) northwest of Brigham City, flows from a small outcrop of fractured Paleozoic limestone with water temperatures ranging from 21° to 23°C (70° to 73°F). Klauk and Budding (1984) reported the TDS content of the water is about 2,000 mg/L, and flow rates of the springs ranged annually from 10,201 to 61,213 L/min (2,244 to13,465 gpm). They also reported that the location recorded by Mundorff (1970) (sec. 2, T.11N., R.4W.) was probably in error, and that Mundorff referred to Bothwell Springs as "Salt Creek Warm Springs." Klauk and

Budding (1984) reported that a salt spring was located and sampled, however, in sec. 6, T.11N., R.3W., about 3.2 km (2 mi) directly east of the location stated for Bothwell. The Utah Division of Wildlife Resources (UDWR) examined these springs in 1999 for possible use as supply water for a warm water fish hatchery (FishPro Inc., 2000). The UDWR eventually dropped this site from further consideration.

Cutler Warm Springs

Cutler Warm Springs were identified in early reports (Mundorff, 1970) as located 16 km (10 mi) northeast of Tremonton, and issuing from Paleozoic limestone within the bed and along the banks of the Bear River, about 1.6 km (1 mi) east of the mapped trace of the Wasatch fault in Box Elder County. Water temperatures reportedly vary between 21° and 27°C (70° and 81°F), and TDS content ranged from 2,000 and 5,000 mg/L. Klauk and Budding (1984), however, reported they could not locate these springs and that they were probably covered as a result of construction of a nearby reservoir.

Chesapeake Duck Club Wells

Goode (1978) reported that in 1925, a 153-m- (502-ft-) deep water well was drilled for the Chesapeake Duck Club in NE¼, NW¼, SW¼, section 27, T.9N., R.3W. The well reportedly produced gas and fluid at a temperature of 74°C (165°F), and was later plugged. Goode (1978) also reported that a second well was drilled to a depth of 152 m (500 ft) and was also plugged due to gas production. No temperature was recorded for the second well. The two wells are located in an area where faulting was noted by Bjorklund and McGreevy (1973, 1974). The faults may be conduits for thermal fluid circulation, which may have been encountered during drilling of these wells (Klauk and Budding, 1984).

Davis No. 1 Geothermal Well

On February 22, 1974, Utah Power & Light Company (now Pacificorp) spudded a geothermal test well in the SW1/4, SW1/4, NW¼, section 16, T.10N., R.2W. in Box Elder County. The well was completed on August 22, 1974 at a depth of 3,354 m (11,005 ft). Temperature logging revealed that the bottom-hole temperature was 105°C (221°F), yielding an overall thermal gradient of 28.3°C/km (1.55°F/100 ft) B much lower than anticipated. Jensen and King (1999) presented three interpretations of the geologic units penetrated by the Davis No. 1 well based on interpretations of cuttings and geophysical logs. They projected the depth to the bottom of valley-fill, Quaternary units between 177 and 207 m (580 and 680 ft). They also projected the depth to the base of Tertiary units (Salt Lake Formation) and the top of pre-Cenozoic rocks (Paleozoic carbonate) at between 1,335 and 1,353 m (4,380 and 4,440 ft). The well penetrated upper Proterozoic rocks (Caddy Canyon Formation) at a fault contact near 2,391 m (7,845 ft). The well penetrated the upper Proterozoic Maple Canyon Formation between 3,179 and 3,228 m (10,430 and 10,590 ft), bottoming in this unit.

Wasatch Front Valleys - Weber River Delta District

The Weber River delta district, in this report, includes that area immediately west of the Wasatch Range, extending southward from the Pleasant View spur at the Weber-Box Elder County line to the Davis-Salt Lake County line near North Salt Lake. The west boundary of Weber River delta district is the eastern shore of the Great Salt Lake. Thermal springs in the area were included in early geothermal studies by Mundorff (1970) and Goode (1978). The area was later the focus of State-Federal sponsored geothermal investigations (Murphy and Gwynn, 1979b; Klauk and Budding, 1984; Klauk and Prawl, 1984; Cole, 1981, 1983).

South Little Mountain Geothermal Area

Murphy and Gwynn (1979b) reported the results of detailed geothermal studies in the "Little Mountain South geothermal area." The reader should refer to their report for more information. The South Little Mountain geothermal area (so termed here to distinguish it from the other "Little Mountain" geothermal area located in Box Elder County to the north) is located about 24 km (15 mi) west of Ogden on the eastern shore of the Great Salt Lake in Weber County. Bear River Bay flows into the Great Salt Lake immediately to the west. Little Mountain is an isolated triangular shaped exposure of Precambrian rock surrounded by valley fill. West of Little Mountain, IMC Kalium Ogden Corp. operates large solar evaporation ponds for extracting potash and salt from Great Salt Lake brine (Bon and Wakefield, 1999). Great Salt Lake Minerals & Chemicals Corp. previously operated the facility and wells were originally recorded with that company name. In addition, Murphy and Gwynn (1979b) reported that other military and commercial facilities are present in the area.

Geothermal manifestations in the area include a few small springs and many, low-temperature flowing wells. The higher temperature wells are located in section 31, T.7N., R.3W. The wells vary in depth from about 122 to 280 m (400 to 920 ft) and penetrate the valley fill, which consists of alternating sand and clay layers. Bolke and Waddell (1972) determined that the wells were completed into four confined aquifers. These aquifers, in general, have higher temperature water and higher TDS with increasing depth. Temperatures in the wells vary from about 25° to 40.5°C (77° to 105°F).

The warm water generally contains less than 1,000 mg/L TDS; the predominant ions are bicarbonate, sodium, and chloride. Bolke and Waddell(1972) suggest that, the low values indicate the water flowing from the wells at South Little Mountain is shallow ground water heated by conduction from an underlying convective hydrothermal system. The underlying system possibly circulates in fractured bedrock. In this model they also postulate that little to no mixing takes place between the two systems (Murphy and Gwynn, 1979b).

Ogden Hot Springs

Mundorff (1970) described the geology, thermal conditions and water chemistry for Ogden Hot Springs. The springs are located at the mouth of Ogden Canyon in SE1/4, SW1/4, SW1/4, section 23, T.6N., R.1W., just east of the City of Ogden in Weber County (figure 7). The springs issue from fractures in Precambrian rocks along the Ogden River. Since people began recording temperatures in the late 1800's, reported temperatures for the springs have ranged from 49° to 66°C (121° to 150°F), but average about 57°C (135°F). Flow rates recorded for the springs have been as high as 379 L/min (100 gpm), although most records indicate that the flow rate is about 132 L/min (35 gpm). TDS content of the sodium chloride-type water from the springs generally varies from 8,650 to 8,820 mg/L. Concentration of manganese is high, and the chemical and thermal characteristics are similar to those for Hooper Hot Springs about 24 km (15 mi) to the southwest.

Hooper Hot Springs and Southwest Hooper Warm Springs

Hooper Hot Springs are located about 16 km (10 mi) southwest of Ogden near the eastern shore of the Great Salt Lake in SE¼, section 27, T.5N., R.3W. in Davis County (figure 7). Mundorff (1970) states that the springs issue from Quaternary deposits, and that they lie about 0.4 km (0.24 mi) west from an inferred fault. In addition to the main hot springs, several small springs and seeps are in the immediate area. Southwest Hooper Warm Springs are located about 0.6 km (0.4 mi) west of the main spring. Mundorff (1970) noted a spring temperature at Hooper Hot Springs of 60°C (140°F) and TDS content of 9,310 mg/L. Temperature of Southwest Hooper Warm Springs was 32°C (90°F) and TDS content was 27,800 mg/L. The water is of sodium chloride-type in both springs. Although calcium concentrations are about the same for both springs, Mundorff (1970) noted that magnesium and potassium concentrations are much higher at Southwest Hooper Warm Springs. Mundorff suggests that the thermal waters at both springs are of the same origin, but water from Southwest Hooper Warm Springs is a mixture of both thermal and shallow ground water.

Wasatch Front Valleys - Salt Lake Valley (Lower Jordan Valley)

Klauk and Darling (1984), assessed of the low-temperature geothermal potential of the lower Jordan Valley (Salt Lake Valley), gathering information mostly on the principal ground-water aquifer of the valley. These workers investigated more that 200 water wells, obtaining temperatures and water analyses throughout the valley. They also gathered thermal gradient data within 30 "holes of opportunity". In addition to presenting existing information on the two known geothermal occurrences (Warm Springs Fault area and the Crystal Hot Springs area, which manifest themselves at the surface) they outlined four areas of thermal ground water that may be indicative of low-temperature thermal anomalies at depth Areas identified as having potential low-temperature geothermal resources are: (1) the north-central valley area, (2) an area immediately north of the Oquirrh Mountains, (3) an east-west oriented portion of the central valley, and (4) a north-south oriented area extending from Draper to Midvale.

Warm Springs Fault Geothermal System

The Warm Springs fault geothermal system extends about 4.9 km (3 mi) in length and 1.2 km (0.75 mi) in width, lying along the base of the Wasatch Range, just north of Salt Lake City (figure 8). The Warm Springs and Hobo faults associated with these springs are local names for segments of the Wasatch fault zone, which forms the boundary between the Salt Lake Valley and the Wasatch Range (Basin and Range and Middle Rocky Mountains Provinces). Beck's Hot Spring, Wasatch Warm Springs, Hobo Warm Springs, and Clark Warm Springs occur along this segment of the fault as well as two, shallow, warm water wells used by local quarry operators. Murphy and Gwynn (1979c) suggested that the thermal springs occur at intersections of the Wasatch fault and older structures that are perpendicular to the fault zone. Discharge temperatures in this system range from 27°C (81° F) at Clark Warm Springs, to 55°C (131°F) at Beck's Hot Spring (Klauk and Darling, 1984).

Crystal (Bluffdale) Hot Springs Geothermal System

The Crystal (Bluffdale) Hot Springs geothermal area is located at the south end of the Salt Lake Valley, near what is called the "Point of the Mountain" (figure 8). Crystal Hot Springs is located in SE¼, NE¼, section 11, T.4S., R.1W., near Utah State Prison. Bluffdale Flower Growers (formerly Utah Roses) operates a geothermal-heated greenhouse complex there (see section on geothermal uses in Utah). Klauk and Darling (1984) reported that surface spring temperatures vary between 55° and 84°C (131° and 183°F). Subsurface temperatures of 88°C+ (190°F+) have been reported in one of two 122-m- (400-ft-) deep production wells. The springs normally issue from valley alluvium into several ponds. When production wells are in operation, the surface springs and ponds reportedly dry up.

Murphy and Gwynn (1979a) studied the geologic aspects of the Crystal Hot Springs geothermal system. The Utah Energy Office (1981) and Morrison-Knudson Company, Inc. (1982) also analyzed technical and economic aspects of the system as part of DOE-sponsored studies in the early 1980s. Klauk and Darling (1984) presented a description of the system in the context of a study of the entire lower Jordan Valley. Crystal Hot Springs is located between two range-front faults with fractured Paleozoic quartzite (at depth) leaking warm water to the surface through unconsolidated material. Temperatures of 55° to 84°C (131° to 183°F) have been measured at the springs, while a production well drilled to supply geothermal water for the Utah State Prison encountered temperatures from 85° to 90°C (185° to 194°F) (Klauk and Darling, 1984).

Utah Roses Geothermal Project

In the early 1980s, Utah Roses, Inc. received funding through a U.S. Department of Energy geothermal program to complete a geothermal production well. The well would be used for space heating a commercial greenhouse in Sandy (a suburb of Salt Lake City). The project originally was to drill and complete a deep (1,220 m [4,000 ft]) well that would produce at least 50°C (122°F) water at a rate of 2,271 L/min (600 gpm). The well was eventually drilled 1,527 m (5,009 ft), producing water at a temperature of 49°C (120°F) at a flow rate of only 757 L/min (200 gpm). As a result of low flows and low temperature, the project was abandoned. However, Utah Roses (now Bluffdale Flower Growers) eventually built a geothermal greenhouse facility at Crystal Hot Springs in southern Salt Lake County (Klauk and Darling, 1984).

Wasatch Front Valleys - Utah and Goshen Valleys

As part of an overall assessment of the geothermal potential of the Wasatch Front, Davis and Cook (1983) performed a detailed gravity survey of Utah County to delineate the structural framework needed to understand geothermal resources within Utah and Goshen Valleys. Utah Valley and Goshen Valley are grabens displaced downward with respect to the Wasatch Range, the West Mountains, and the Oquirrh-Boulter-Tintic fault block to the west. The greatest depth to bedrock is probably in the southern part of Utah Valley, where Davis and Cook (1983) interpreted the depth to Paleozoic rocks to be about 4,175 m (13,700 ft). The depth to bedrock in the complexly faulted Goshen Valley graben was interpreted to be more than 1,890 m (6,200 ft). Modeling of the gravity data indicated the association of (1) Saratoga Hot Springs, Lincoln Point Warm Springs, Crater Hot Springs, and Warm Springs at Bird Island with the Utah Lake fault zone; (2) Goshen Warm Springs with the Long Ridge fault; and (3) other warm springs with other fault zones. Their gravity studies substantiate the idea that most of the springs in Utah Valley are fault controlled (Klauk and Darling, 1984).

Klauk and Davis (1984) performed a temperature survey and chemical analyses of wells and springs in Utah and Goshen Valleys as part II of the project described in the previous paragraph. As a result of their work, they identified five areas in Utah County warranting further investigation for low-temperature geothermal resources. One area in northern Utah Valley coincides with the Utah Lake fault zone and includes Saratoga Hot Springs. Water temperatures within this area range from 21° to 43°C (70° to 109°F). Two other geothermal areas in southern Utah Valley are also spatially related to the Utah Lake fault zone (including Lincoln Point-Bird Island, and an area north of Payson), and based on water chemistry, appear distinguishable from the other waters in the valley. Temperatures for these two areas range from 21° to 32°C (70° to 90°F) (Klauk and Darling, 1984). The fourth area includes Castilla and Thistle Hot Springs (see section on Wasatch and Uinta Mountains) located in Spanish Fork Canyon where spring temperatures approach 50°C (122°F). The fifth area lies in Goshen Valley and includes a group of water wells and Goshen Warm Springs ranging in temperature from 20 to 27°C (68° to 81°F).

Saratoga Hot Springs

Saratoga Hot Springs issue from unconsolidated Quaternary deposits along the northwest shore of Utah Lake in SE1/4, SW1/4, section 25, T.5S., R.1W. in Utah County (figure 8). Other hot springs, known locally as Crater Springs, issue beneath Utah Lake about 0.8 km (0.5 mi) east of Saratoga Springs. Infrequent measurements since the early 1900s show that spring temperatures have ranged from 38° to 44°C (100° to 111°F). The springs are spatially related to the trend of the Utah Lake fault zone (Mundorff, 1970). Klauk and Davis (1984) report that water from Saratoga Hot Springs is calcium-sodium chloride-sulfate-bicarbonate type, slightly acidic to slightly basic, and slightly saline with TDS ranging from 1,428 to 1,790 mg/L.

Lincoln Point Warm Springs

Lincoln Point Warm Springs are located in section 2, T.8S., R.1E. along the southern shore of Utah Lake at the north end of West Mountain (figure 8), a complex north-south trending, steep-sided horst. Here, Paleozoic limestone and quartzite of the Oquirrh Formation are folded and fractured by numerous faults. The Cretaceous-Tertiary North Horn Formation underlies slope-wash clay and gravel, and overlies Paleozoic rocks. Springs discharge warm, saline water from gravels along the shoreline. Abundant travertine and tufa deposits are associated with the springs (Baskin and others, 1994). Temperatures of the springs range from 25° to 32°C (77° to 89°F). The waters are strongly sodium chloride with TDS content at about 6,000 mg/L (Mundorff, 1970).

Bird Island Warm Springs

Bird Island is a small island in Utah Lake located about 3.2 km (2 mi) north-northeast of Lincoln Point. The island consists of travertine and tufa deposits with wave-worked, rounded travertine and tufa gravel along the island beaches. Warm, saline springs (located at SE¼, NW1/4, SW1/4 section 26, T.7S., R.1E.) discharge at temperatures between 30° and 32°C (86° and 90°F) from the edge of the island and beneath the surface of Utah Lake (Baskin and others, 1994). The spring water is strongly sodium-chloride type with TDS ranging from 6,300 to 7,400 mg/L.

Goshen Warm Springs

Goshen Warm Springs are about 3.2 km (2 mi) east of Goshen and about 4.8 km (3 mi) southwest of Santaquin in Utah County. The springs issue from colluvium directly west of the Long Ridge fault zone in SW¼, section 8, T.10S., R.1E. Klauk and Davis (1984) recorded a surface temperature is 21°C (70°F) and TDS content of 1,298 mg/L, and according to Mundorff (1970) the water is strongly sodium chloride. A number of warm wells are also present in the vicinity. The Utah Division of Wildlife Resources has considered developing a warm-water fish hatchery at Goshen Warm Springs to raise warm-water sport fish and other native aquatic species.

Northwestern Utah

Hydrothermal systems revealed by thermal springs and wells are scattered throughout this large, sparsely populated region of northwestern Utah, which includes all of northern and western Box Elder County. The region generally covers the area northwest of the Great Salt Lake, from the Promontory Mountains to the Raft River Range. Mundorff (1970) included information on thermal springs and general geology in northwestern Utah as part of his report on major thermal springs in the state. Goode (1978) also reported on thermal springs in Grouse Creek and Hansel Valley as part of an overall study of thermal waters in Utah.

Grouse Creek - Raft River

The Grouse Creek - Raft River area lies in the northwest part of Box Elder County and includes the Grouse Creek drainage and the southern flank of the Raft River Mountains. Hood and Price (1970) and Goode (1978) describe a hot spring (Warburton Spring) yielding 852 L/min (225 gpm) of low TDS water (248 mg/L) located in NE¼, NW¼, section 11, T.11N., R.19W. Goode (1978) describes the spring as issuing from Paleozoic rocks in a tributary (?) of Grouse Creek (Death Creek). These authors also describe another thermal spring 20°C (68°F) near Kimber Ranch, in NE¼, SE¼, section 30, T.10N., R.18W., also in the Grouse Creek drainage. Hood (1971) reports on a thermal spring in NE¼, NE¼, section 19, T.12N., R.15W. that flows 26.5°C (80°F), low-TDS water (223 mg/L) at a rate of 1,287 L/min (340 gpm). Several other springs in the area issue at temperatures from 20° to 23°C (68° to 73°F).

Curlew and Hansel Valleys

Davis and Kolesar (1984) studied the hydrology of north-central Box Elder County as it relates to thermal springs and wells in and around Curlew and Hansel Valleys. They recorded the highest water temperatures of 31°C (88°F), 30°C (86°F), and 29°C (84°F) in separate geographic regions. TDS contents range from 294 to 11,590 mg/L, but are generally greater than 1,100 mg/L. The warmer thermal waters are sodium-chloride type.

Both the Hansel and Promontory Mountains are bounded by north-northeast trending normal faults. Hansel Valley is a graben lying between the two ranges. Movement along the range-bounding faults is documented. In 1934, Hansel Valley was the site of the largest earthquake (6.6 magnitude) in Utah's recorded history.

Davis and Kolesar (1984) reported that a normal fault occurs along the east side of Curlew Valley. They also suggested that, based upon gravity data from Cook and others (1964), a system of north to northeast-trending normal faults is present throughout the central part of the valley and the Wildcat Hills. Howes (1972) mapped ring structures in the Wildcat Hills consisting of curved perlite dikes. Howes (1972) also found compound basaltic necks with well-developed columnar joints and volcanic vents that once extruded perlite and rhyolite.

Davis and Kolesar (1984) identified five areas with possible potential for commercial geothermal resources. These include (1) the area they refer to as "area A" in the northern Curlew Valley, (2) the area they refer to as "area B" in Hansel Valley just adjacent to the northwest edge of the Promontory Mountains, (3) an area 8 to 16 km (5 to 10 mi) north of the Wildcat Hills, (4) the western edge of the northern Promontory Mountains east of Snowville, and (5) the western edge of the Hansel Mountains in T.13N., R.8W., and T.12N., R.8W.

Blue Creek Springs

Blue Creek Springs are located in Box Elder County north of the Promontory Mountains in Blue Creek Valley in section 29, T.13N., R.5 W. (Bolke and Price, 1972). Springs emerge from the north end of Anderson Hill at temperatures between 27° and 29°C (81° and 84°F) and flow southward into Blue Creek Reservoir. Cole (1983) reported that the springs issue at a flow rate of about 1,800 L/min (480 gpm), and the fluids contain about 2,000 mg/L TDS. Goode (1978) reported a much higher flow of 21,276 L/min (4,680 gpm) from the springs. The UDWR recently completed feasibility studies for developing a warm-water hatchery to raise sport fish and native threatened and endangered fish at Blue Creek Springs (FishPro Inc., 2000). The Division eventually rejected the site from further consideration.

Great Salt Lake Desert and Western Valleys

Hydrothermal systems indicated by thermal springs and wells are scattered throughout this large, sparsely populated region of Utah, which includes western Tooele County. The region extends westward from the Cedar Mountains in central Tooele County across the Bonneville Salt Flats to the Nevada-Utah state line, and then southward into Snake and Tule Valleys of Juab and Millard Counties. Mundorff (1970) included information on thermal springs and general geology for the Great Salt Lake Desert and western Utah as part of his report on major thermal springs in the state. Goode (1978) also reported on thermal springs in this region as part of an overall study of thermal waters in Utah.

Blue Lake Spring and Bonneville Salt Flats

Low-temperature thermal waters are present in the western part of the Great Salt Lake Desert, as recorded in wells used for brine production and mineral extraction around the Bonneville Salt Flats, and as thermal springs at Blue Lake and Salt Spring. Turk (1973) presents data on 13 "deep brine wells" drilled to depths ranging from 326 m to 631 m (1,070 to 2,070 ft). The highest temperature recorded was 88°C (190°F), measured in the drilling mud of one well designated as "DBW-3" while circulating at a depth of 499 m (1,637 ft). The brine produced from these deep wells contains 120,000 to 130,000 mg/L TDS.

Blue Lake and Salt Spring, located in western Tooele County near the Utah-Nevada border, are small lakes fed by thermal springs. Although the temperatures of the spring vents (located beneath Blue Lake) are not known, the temperature of Blue Lake is fairly constant at about 29°C (84°F). The area, which includes a small parcel of private land, adjacent to a state wildlife preserve, both enclosed by a military reservation, is valuable for the recreational opportunities offered in the form of year-round diving, and as a wildlife habitat.

Skull Valley - Tooele Valley

Thermal springs occur along the east and west flanks of the Stansbury Mountains in Tooele County, just south of the southern shoreline of the Great Salt Lake. Thermal springs issue from fractured bedrock and alluvium at temperatures ranging from 19° to 22.7°C (66° to 73°F) from the northern edge of the range and along its western side. Big Warm Springs, located on the northern edge of the range in SE¼, SE¼, section 8, T.1S., R.7W., issues at high flow rates of over 11,400 L/min (3,000 gpm) at a temperature of 19°C (66°F). The water is strongly sodium chloride with a TDS concentration of about 7,150 mg/L. Several other springs with similar type waters issue along the western flank of the Stansbury Range at temperatures of about 23°C (73°F). The alignment of springs and other evidence suggests the presence of a buried Quaternary fault (Mundorff, 1970).

At Grantsville Warm Spring, located about 5 km (3 mi) northwest of Grantsville in Tooele County (figure 4), springs issue from lake-bed sediments at a combined discharge rate of about 1,510 L/min (400 gpm) at temperatures from 24° to 32°C (75° to 90°F). Water chemistry of the springs approach the salinity of sea-water with TDS concentration of about 26,500 mg/L. Bonneville SeaBase, a commercial SCUBA diving facility developed at Grantsville Warm Springs, is located about 64 km (40 mi) west of Salt Lake City. SeaBase consists of several dive pools, stocked with tropical marine fish, fed by thermal water from Grantsville Warm Springs.

Fish Springs Flat

Hot springs also issue in and along the margins of Snake Valley, Tule Valley, and Fish Springs Flat of western Utah. Wilson Health Springs, the site of an abandoned resort of the same name at the north end of the Fish Springs Range (figure 4), issues from small mounds at temperatures approaching 60°C (140°F), with flow rates varying up to 380 L/min (100 gpm). Thermal fluids at Wilson are moderately saline with TDS content slightly over 21,000 mg/L (Blackett, 1994). Chemical geothermometers suggest equilibration temperatures of less than 100°C (212°F). The Fish Springs National Wildlife Refuge lies along the northeast flank of the Fish Springs Range. These broad wetlands are fed by a number of springs with temperatures ranging between 20° and 29°C (68° and 84°F). Wilson Health Springs is the northernmost, and hottest, of a series of north-trending, warm springs.

Tule Valley

Several thermal springs issue at temperatures between 24° and 31°C (75° and 88°F) near the basin floor in Tule Valley. The springs lie along a north-northeast trend suggesting that their position is related to a buried fault or fault zone (Stephens, 1977).

Snake Valley and Gandy Warm Springs

Four springs and four wells scattered throughout Snake Valley issue low-temperature water from 20° to 27°C (68° to 81°F). The warmest of these - Gandy Warm Springs (SW¼, SE¼, section 31, T.15S., R.19W., Millard County) - issues from near the base of the southern part of the Deep Creek Range near the Utah-Nevada border (figure 4). The Utah Division of Wildlife Resources recently completed feasibility studies for developing a warm-water hatchery to raise sport fish and native aquatic species. As a result of the study, Gandy Warm Springs ranked highest among five candidate sites for establishing a warm-water hatchery using water-quality, water-quantity, and land-suitability criteria (FishPro Inc., 2000).

Sevier Thermal Area

Mabey and Budding (1987) proposed the name "Sevier thermal area" for a region of southwest Utah where all of the state's known moderate- and high-temperature (>90°C [194°F]) hydrothermal systems occur. The Sevier thermal area (figure 5) covers a portion of the eastern Basin and Range Physiographic Province, and part of the Basin and Range-Colorado Plateau transition zone. The area, which includes all of the Sevier, Black Rock, and Escalante Deserts of southwestern Utah, is characterized by (1) abundant late Cenozoic normal faults, (2) Tertiary plutonic and volcanic rocks and Quaternary basalt, (3) high regional heat flow, and (4) a complex structural history. The Intermountain seismic belt, a north-south oriented zone of active seismicity (Smith and Sbar, 1974), traverses the eastern portion of the Sevier thermal area. The east-west-oriented southern Nevada seismic belt intersects the Intermountain seismic belt near Cedar City.

Sevier and Blackrock Deserts

Ross and others (1993) described the geothermal setting of the Black Rock and Sevier Deserts in Millard and Juab Counties and present the results of self-potential studies at the Meadow-Hatton geothermal area and at the Crater Springs KGRA. The Sevier and Black Rock Deserts are contiguous, complexly faulted structural basins that have characteristics similar to other basins in the Basin and Range province (figure 5). The Sevier Desert detachment, a gently (3 to 4 degrees) westward-dipping detachment surface, separates shallow (< 5 km [3 mi]) extensional structures from deeper, pre-Basin and Range structures (Allmendinger and others, 1983; Anderson and others, 1983; Planke and Smith, 1991). Mountain ranges on the east and west bound low-lying valleys that are underlain by thick sedimentary fill that thins toward the basin margins. Listric and planar faults that die-out upward into the basin fill separate the main part of the Sevier and Black Rock Desert basins into a number of buried, smaller basins.

A series of bimodal volcanic rocks, ranging in age from Pliocene (2.7 Ma) through Holocene (< 1 ka) are aligned roughly north-south through the Sevier and Black Rock Deserts. Pliocene volcanic rocks (2.1 Ma to 2.7 Ma) located in the southern part of the Black Rock Desert consist of basalt, rhyolite, and rhyodacite. Quaternary volcanic units are mainly basalt flows ranging in age from about 1.5 Ma at Beaver Ridge to less that 1,000 years B.P. at Ice Springs. A small rhyolite dome at White Mountain, dated by Nash (1986) at 0.4 Ma, is considered the youngest rhyolite flow in Utah. Younger Quaternary basaltic rocks include the Pavant Ridge basalt (0.22-0.16 Ma) and ash erupted from Pavant Butte (15,000 years B.P.); basaltic flows, tuff, and cinders from the Tabernacle Hill vent (14,300 years B.P, figure 9); and the Ice Springs basalt flow (660 years B.P). The basalt of Tabernacle Hill erupted into Lake Bonneville at or near the Provo shoreline and exhibits features typical of basaltic eruptions into water. Quaternary basaltic units in the central and northern Sevier Desert include the Deseret basalt flows (0.4 Ma) and the basalt flows and scoria at Fumarole Butte and Crater Bench (0.9 Ma) in the Crater Springs KGRA (Oviatt, 1989; Oviatt and others, 1991).

Oviatt (1991) mapped numerous, north-northeast-oriented faults cutting Quaternary units in the Black Rock Desert. The Pavant-Tabernacle-Beaver Ridge fault zone is a broad zone of faults primarily cutting the Beaver Ridge and Tabernacle Hill flows. The Ice Springs basalt, the youngest volcanic unit, is not cut by faults within this zone. Faults in the southern extension of the Clear Lake fault zone and faults near Hatton Hot Springs cut post-Lake Bonneville deposits, and therefore have probably been active throughout the Quaternary. Faults in the Cove Creek dome area cut Tertiary basalt flows and lie along the same structural trend as the Pavant-Tabernacle-Beaver Ridge fault zone.

A doubly-plunging anticline in Tertiary basalt and Quaternary lacustrine deposits to the south of Twin Peaks is known as the Cove Creek dome. Crecraft and others (1981) reported about 400 m (1,300 ft) of uplift of lacustrine limestone near Cove Creek. Oviatt (1991) postulated that the distribution of the lacustrine units indicated that the Cove Creek dome was uplifted approximately 300 to 400 m (1,000 to 1,300 ft), and while most of the uplift probably took place during the late Tertiary, other evidence suggests that uplift continued after late Tertiary and may be as young as Holocene.

Abraham (Baker, Crater) Hot Springs

The Crater Springs geothermal area surrounds a Quaternary eruptive center known as Fumarole Butte in the northern Sevier Desert of Juab County (figure 10). Early Pleistocene basalt flows (0.9 Ma) erupted from the vent area and formed a broad volcanic apron now known as Crater Bench. The Drum Mountains fault zone, a north-northeast trending zone of high-angle normal faults, offsets basalt flows along the west-central side of Crater Bench at Fumarole Butte. Warm vapor rises from several fissures in the vicinity of Fumarole Butte. Abraham Hot Springs, also referred to in literature as "Crater Springs" or "Baker Hot Springs," issues 8 km (5 mi) to the east of Fumarole Butte along the east margin of the Crater Bench basalt flows. Mabey and Budding (1987) postulated that the vapor venting from Fumarole Butte and the thermal waters at Abraham Hot Springs are part of the same geothermal system.

Temperatures at Abraham range up to 87°C (189°F). Rush (1983) estimated total flow rates from about 40 spring orifices at between 5,400 and 8,400 L/min (1,400 and 2,200 gpm). The geologic structure controlling the system is unknown, and the reservoir temperature is uncertain. Samples of cold springs issuing from the same site were collected for analyses as part of this study in order to develop more accurate mixing models. Analyses of the cold water, however, revealed that this water is very similar in composition to that of the hot springs, and suggests that the cold springs are merely cooled hot water. According to the classification of Back (1961), the thermal water is sodium calcium-chloride type. Geothermometers suggest equilibration temperatures in the range 87° to 116°C (189° to 241°F).

Meadow and Hatton Hot Springs

The Meadow-Hatton area (figure 11) is located less than 2 km (1.3 mi) west of Interstate Highway 15 in Millard County. Fillmore, the county seat with a population of 2,000 people (1990 census), is located about 10 km (7 mi) to the northeast. The small community of Meadow (population 250, 1990 census) is situated on Interstate Highway 15, less than 2 km (1.3 mi) from the thermal area. The Pavant Valley and the Black Rock Desert comprise mostly irrigated croplands. Land ownership in the Pavant Valley and Black Rock Desert is a combination of private, state, and federal parcels.

The Meadow-Hatton geothermal area (figure 11) consists of a large travertine mound, marshland, and thermal springs located about 16 km (10 mi) southwest of the town of Fillmore on the east side of the Black Rock Desert in Millard County. The Black Rock Desert contains some of the state's youngest volcanic rocks -- some being only a few hundred years old. Hatton Hot Spring issues from the south end of a large, northeast-trending travertine mound at a temperature of 63°C (145°F). Meadow Hot Springs, comprising several thermal springs in a northeast alignment and located in a marshy area about 2 km (1.3 mi) northwest of the Hatton travertine mound, issue at temperatures up to 41°C (106°F). Flow rates from the springs are low and reportedly vary from 0 to 240 L/min (63 gpm). The spring waters are probably coupled to the regional ground-water flow system of the Pavant Valley and Black Rock Desert.

Ross and others (1993) described two fluid samples from the Meadow Hot Springs area (MI-080 and MI-082) in conjunction with the results of self-potential surveys completed in the area. Self-potential surveys revealed a high-amplitude, negative anomaly beneath the southern part of the travertine mound. More recent chemical data show very different values for potassium, silica, and fluoride concentrations compared to earlier data, suggesting temporal variations in spring chemistry. Standard geothermometers range between 205°C (401°F) (Na-K-Ca) and 86°C (187°F) (Na-K-Ca-Mg), with most likely equilibration temperatures around 108°C (226°F) (quartz conductive). Based on the results of the new chemical analyses, the fluids appear to be highly evolved with a very complex thermal history (Ross and others, 1993).

Neels Area

An area near the Neels railroad siding northeast of the Cricket Mountains is a geothermal enigma. Lee (1908) described events during drilling of a 609 m (2,000 ft) water-supply well in 1906 near Neels by the San Pedro, Los Angeles, and Salt Lake Railroad. During drilling, hot water was encountered at several horizons, and steam apparently vented continually from the well-bore. Reportedly, some oil was encountered, and a pocket of gas was penetrated at a depth of 549 m (1,802 ft). The well was eventually abandoned because of drilling difficulties and poor water quality.

An intriguing bit of information was a water analysis on a sample taken from a depth of 426 m (1,398 ft) (Lee, 1908). The sample had a TDS content of 3,345 parts per million and reported "siliceous matter" (presumably SiO_2) content of 370 parts per million. Silica geothermometers applied to the latter value yield an equilibrium temperature of over 200°C (392°F), suggesting the possibility of a high-temperature reservoir somewhere in the subsurface. Two other water samples taken at horizons both above and below the 426-m (1,400-ft) depth yielded more normal values for silica.

Cominco American, Inc. completed a deep test well (2 Beaver River) to a depth of 4,021 m (13,193 ft) near the Neels siding in 1980. The well reportedly penetrated an unconformity at 610 m (2,000 ft) and Precambrian rocks at 756 m (2,480 ft). The well also penetrated a thrust fault at 2,557 m (8,390 ft), continued in lower Paleozoic rocks to total depth, and probably bottomed in Cambrian Tintic Quartzite (Utah Division of Oil, Gas and Mining well files). Geophysical logs indicate that a bottom hole temperature of 153°C (308°F) was measured five hours after circulation of the drilling mud was stopped. This well was later plugged back to 180 m (600 ft) and converted to a water well.

Cove Fort-Sulphurdale

The Cove Fort-Sulphurdale geothermal area lies on the northwest side of the Tushar Mountains, and is roughly 32 km (20 mi) north along Interstate Highway 15 from the town of Beaver (figure 12). The Tushar Mountains consist primarily of mid-Tertiary quartz latite and alkali rhyolite ash-flow tuffs of the Marysvale volcanic field. To the north, the Pavant Range consists of thrusted pre-Tertiary sedimentary rocks and tilted Tertiary sediments. Tertiary volcanics of the Marysvale field overlap the pre-Tertiary sedimentary rocks on the south end of the Pavant Range. A large basaltic andesite flow of Pleistocene age lies a few kilometers to the west of the geothermal area (Hintze, 1980; Mabey and Budding, 1987).

Ross and Moore (1985) described the results of previous geological investigations, presented the findings of detailed geophysical studies, and proposed a conceptual model for the geothermal system at Cove Fort. They characterized the system as resulting from a combination of complex geologic structures that localize the geothermal source. The oldest structures are Sevier-age thrust faults, mapped to the north in the Pavant Range and penetrated by deep drilling at Cove Fort. Moore and others (1979) reported that one deep drill hole (Utah State 31-33, MI-097 on figure 12) at Cove Fort intersected Paleozoic dolomite thrust above Triassic siltstone and limestone.

Basin and Range tectonism produced numerous north-northeast-striking high-angle normal faults, in addition to large penecontemporaneous gravitational slide blocks. The gravity-slide blocks are low-permeability layers that cap portions of the geothermal system. At the surface, the trends of faults are delineated by local alignments of sulfur deposits, acid-altered alluvium, and gas seeps. The surface manifestations occur throughout an area of about 47 square kilometers (18 mi^2) and probably reflect boiling and degassing of chloride-rich brine from a thermal water table 400 m (1,300 ft) below the surface. Dry steam at about 150°C (300°F) is produced from relatively shallow production wells (180-

400 m [600-1,300 ft] deep) completed into fractured reservoir rocks near Sulphurdale.

Mother Earth Industries, Inc. installed the first power-generation facility at Cove Fort in 1985. It originally consisted of four binary-cycle power units with a total capacity of 3 MW (gross). The power system was later supplemented by a turbine generator (2 MW gross), placed upstream from the binary units in order to take better advantage of the temperature and pressure conditions of the producing reservoir. In the fall of 1990, the City of Provo in cooperation with the Utah Municipal Power Authority (UMPA), dedicated the Bud L. Bonnett geothermal power plant at Cove Fort. The Bonnett plant is referred to here as the UMPA Cove Fort Station No. 1 plant. The plant, rated at 8.5 MW (gross), became the third geothermal power facility owned by UMPA and Provo to go on-line at the Sulphurdale field. Because H_2S is produced as a non-condensable component of the dry steam, the facility includes a sulfur abatement plant designed to produce 1.36 metric tons (1.5 tons) per day of sulfur (Geothermal Resources Council, 1990).

A total of six production wells (three 18-cm- [7-in] diameter wells and three 33-cm [13-in] diameter wells) supply steam to the three power units. Although specific information is not available, steam supply wells reportedly produce from the shallow, vapor-dominated part of the geothermal system, at depths between 335 and 366 m (1,100 and 1,200 ft). Reductions of reservoir pressures necessitated that the developers drill and complete new production wells into the deeper, liquid-dominated portion of the system. The estimated net output from all three power units is about 10 MW (Richard Judd, UMPA; and Jay Hauth, consultant, personal communication, 1991).

Escalante Desert

The Escalante Desert (figure 5) is a northeast-southwest elongate basin measuring approximately 120 by 45 km (75 by 28 mi) that includes much of the Sevier thermal area as defined by Mabey and Budding (1987). Mountains and hills composed primarily of Tertiary ash-flow tuff and younger volcanic flows and domes surround it. Ash-flow tuff units range in age from 32 to 19 Ma. Rhyolite and dacite flows and domes range in age from 13 to 8.5 Ma (Rowley and others, 1979). Upper Tertiary and Quaternary unconsolidated and semi-consolidated material, likely more than 1.6 km (1 mi) thick, fill the deeper parts of the valley (Blackett and others, 1990).

The Escalante valley lies between two major, roughly east-west-oriented igneous belts, also known as mineral belts. The Pioche-Marysvale igneous belt (Oligocene) lies to the north, and the Delamar-Iron Springs igneous belt (Miocene) lies to the south. Rowley and others (1979) suggest that the Pioche-Marysvale and the Delamar-Iron Springs igneous belts are structurally controlled, and are associated with two east-west-oriented lineaments that coincide with the igneous belts -- the Blue Ribbon lineament to the north and the Timpahute lineament to the south (figure 5).

Gravity studies by Pe and Cook (1980) suggest the presence of many Basin and Range block-faulted structures buried beneath the Escalante Desert. However, the Antelope Range fault located on the southeast side of the valley is the only large-scale, mapped fault showing displacement during the Quaternary (Anderson and Christenson, 1989).

The principal water-bearing unit of the Escalante Valley consists of unconsolidated and semi-consolidated materials of Quaternary age. Another ground-water source consists of water in Tertiary volcanic rocks along the low-lying margins of the Escalante Valley (Mower, 1982). Ground-water use for irrigation from the principal water-bearing unit of the Escalante Valley has modified the natural subsurface drainage patterns. Subsurface water in the southwest part of the valley discharges to a large water-table depression near the community of Beryl Junction. Subsurface water within the northeast portion of the valley discharges to the northeast, the natural drainage direction, toward the Milford area. Recharge to the ground-water system is from subsurface inflow from bedrock as well as inflow from stream channels. Recharge is also from irrigation and direct precipitation (Klauk and Gourley, 1983).

Roosevelt Hot Spring Geothermal Area

The Roosevelt Hot Springs KGRA, situated on the west side of the Mineral Mountains along the northern edge of the Escalante Desert (figure 13), is the most studied geothermal area in Utah. Geothermal resources at Roosevelt Hot Springs have been of commercial interest since the early 1970s, and have been actively developed for power generation since the late 1970s. Ward and others (1978) and Ross and others (1982) presented geological, geophysical, and geochemical data for the Roosevelt Hot Springs geothermal area. Mabey and Budding (1987) summarized the findings of the previous workers at Roosevelt.

The geologic setting of the Mineral Mountains is unusual with respect to other ranges in the region. The range consists mostly of a Tertiary pluton with six major phases of quartz monzonitic to leucocratic granitic rocks, two diorite stocks, and several types of mafic dikes, thought to be the intrusive equivalents of the Mount Belknap volcanics (21 to 16 Ma) in the Tushar Mountains. Price and Bartley (1990) described a major, low-angle, gently arched, normal fault along the west flank of the Mineral Range. This structural detachment zone places hanging-wall Paleozoic and Mesozoic

sedimentary rocks and Tertiary volcanic rocks against footwall Tertiary intrusive rocks. They suggested a structural history involving east-west extension that produced the low-angle detachment zone and high-angle east-west-oriented faults. Continued east-west extension eventually produced north-south-oriented, high-angle normal faults which cross-cut the older detachment and high-angle east-west structures. Quaternary rhyolitic volcanism (0.8 to 0.5 Ma) occurred in the central part of the range (Lipman and others, 1978) and basaltic flows later (70,000 to 10,000 years ago) occurred to the north (Sibbett and Nielson,
1980).

Heat-flow studies by Wilson and Chapman (1980) identified an area of anomalous heat flow extending about 5 km (3 mi) wide and 20 km (12 mi) long over the Roosevelt Hot Springs geothermal area. Heat-flow values in excess of 1,000 mW/m^2 enclose an area roughly 2 km (1.2 mi) wide by 8 km (5 mi) long that is thought to coincide with the near-surface part of the geothermal system. Using gravity data, Becker and Blackwell (1993) infer a deep, cylindrically shaped, anomalous mass approximately 10-15 km (6-9 mi) in diameter situated about 5 km (3 mi) beneath the geothermal field to be a young intrusion.

Production from the Roosevelt geothermal area is primarily from highly fractured Tertiary granite and Tertiary (?) metamorphic rocks. The fracturing within the geothermal reservoir appears to be associated with the intersection of a system of north-south trending Basin and Range normal faults with somewhat older east-west oriented structures (Mabey and Budding, 1987).

Utah Power (a Pacificorp company) operates the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area (figure 13 and figure14). Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from four wells that tap a production zone in fractured, crystalline rock. The production zone depths range generally between 640 and 1,830 m (2,100 and 6,000 ft). This zone is reportedly tilted to the west, probably reflecting westward down-stepping of crystalline reservoir rocks by Basin and Range faulting. Reservoir temperatures are typically between 270° and 315°C (520° and 600°F) (Blackett and Ross, 1992).

Wellhead separators, which are used to "flash" the geofluid and partition it into liquid and vapor phases, are installed on each of the production wells. The liquid phase, or geothermal brine, is channeled back into the reservoir through three gravity-fed injection wells. The vapor phase, or steam-fraction, is collected from the four wells and directed into the power plant. After exiting the power plant, the spent steam flows through a condensing unit, and the resulting condensate is also discharged to the injection wells (Monte Nolan, Utah Power, personal communication, 1991).

The temperature of the steam upon entering the Blundell plant ranges between 177° and 204°C (350 and 400°F), with steam pressures approaching 7.7 kg/cm^2 (109 psi). The plant produces 26 MW gross output (23 MW net) with all four wells operating. Roughly two percent of the vapor phase is non-condensable gas, which is vented to the atmosphere (Kit Wareham, Utah Power, personal communication, 1991).

Thermo Hot Springs Area

The Thermo Hot Springs geothermal area is located within the northeast part of the Escalante Desert in southern Beaver County (figure 15). Thermal water discharges from two large spring mounds, consisting primarily of cemented windblown quartz sand and silt, situated near the axial drainage of the Escalante Desert valley. The Shauntie Hills, located to the northwest, and the Black Mountains, located to the southeast, consist largely of volcanic mudflow deposits, mudflow breccias, and lava flows of dacitic and rhyodacitic composition. Rocks in the Black Mountains and the Shauntie Hills probably erupted from separate, although possibly time-equivalent (Miocene, 29 to 19 Ma) strato-volcanos. Rowley (1978) mapped an exposure of rhyolite 3.2 km (2 mi) to the east of the hot spring mounds, for which he obtained a date of 10.3 Ma.

Northeast-oriented normal faults that displace Quaternary valley-fill units and form a broad zone of faulting, are mapped along the hot spring mounds and elsewhere in the vicinity. Faults mapped within the volcanic units of the low hills southeast of the thermal area, and within the Black Mountains, exhibit a dominant northwest orientation. The orientation of these two sets of structures and the position of the hot springs led Rowley and Lipman (1975) to suggest that a structural intersection localized the geothermal system. Based upon the regional gravity data of Sawyer and Cook (1977) and Cook and others (1981), Mabey and Budding (1987) postulated that a subsurface fault with several hundred feet of displacement (down to the west) passes through the hot springs area.

Mariner and others (1978) reported a temperature of 89.5°C (193.1°F), and discharge rates between 30 and 120 L/min (8 and 32 gpm) at Thermo Hot Springs. Blackett and Ross (1992) reported a much reduced flow. Klauk and Gourley (1983) reported spring temperatures ranging from 42 to 78°C (108 to 172°F), and the results of water analyses on four spring samples. Klauk and Gourley (1983) indicated that the Thermo water is sodium-calcium chloride-sulfate-bicarbonate in character and enriched in Na, K, and SO_4. They also reported quartz-conductive geothermometer temperatures, ranging from 128 to 131°C (262 to 268°F).

Republic Geothermal, Inc. contributed temperature-gradient, geophysical, and geochemical data in support of geothermal studies in the area. The data package includes primarily information from temperature-gradient boreholes and water analyses, as well as production test and temperature data from a deep (2,221 m [7,288 ft]) exploratory drill hole. The distribution of anomalous temperature gradients indicates warmer shallow temperatures in the vicinity of the hot springs. Although most of the thermal gradient holes are shallow and relatively widely spaced, the temperature data indicate that anomalous temperatures may extend eastward several thousand feet from the spring mounds.

Ross and others (1991a) performed self-potential (SP) surveys near Thermo Hot Springs to determine the SP expression of the geothermal system. The SP surveys, covered an area of approximately 10.4 square kilometers (4.0 mi^2) and showed no outstanding anomalies across the two spring mounds. A broad, complex SP low, however, occurs in the southeast part of the area near the Minersville road, approximately 1.6 km (1 mi) southeast of the southern mound. The anomaly occurs over alluvium, perhaps 15 m (50 ft) above the level of the valley floor. No drill hole or geophysical data are available in the immediate area to give any insight into the probable source of the SP anomaly. The anomaly occurs on the up-thrown side of a mapped, northeast-oriented fault, and its shape somewhat mimics the topography of an overlying alluvial fan, suggesting some contribution from fluids within or beneath this fan. Northwest-oriented drainage patterns and similarly oriented faults mapped in bedrock to the south and southeast suggest the source could occur at a buried fault intersection.

Newcastle Geothermal Area

The Newcastle area (figure 16) is located near the south end of the Escalante Valley in Iron County. The area is underlain by an aquifer containing low- and moderate-temperature geothermal fluid, and construction of new commercial greenhouse facilities is increasing use of the geothermal aquifer. The UGS and the University of Utah (U of U) analyzed 27 thermal-gradient drill holes, and performed geophysical surveys, and geologic mapping and wrote an assessment of the resource (Blackett and Shubat, 1992). UGS and U of U continue to monitor the Newcastle Geothermal System (Blackett and others, 1997).

The unincorporated town of Newcastle -- located near State Highway 56 connecting Cedar City, 48 km (30 mi) to the east, to a number of small communities in the Escalante Valley to the west --

lies just north of the center of the geothermal system. Geothermal water is used to heat an LDS chapel in the town. Cedar City is situated along Interstate Highway 15, and is served by a Union Pacific rail-line and a scheduled-service airport. The Escalante Valley is an agricultural region that produces potatoes, alfalfa, corn, and livestock.

A maximum temperature of 130°C (266°F) was measured in a geothermal exploration well, which penetrated the geothermal aquifer (outflow plume). Production wells at the greenhouses generally produce fluids in the range of 75°C to 95°C (167°F to 203°F). Geothermometers suggest maximum resource temperatures of up to 166°C (331°F), with more common temperatures of 140° to 150°C (284° to 302°F).

Geothermal production wells tap an unconfined, alluvial aquifer, which contains hot water and covers an area of several square miles. Thermal water originates from a buried point-source near a range-front fault, and spills into the aquifer. The fluids cool by conduction and probably mix with shallow groundwater at the system margins.

Beryl Area

The Beryl area is located within the southern Escalante Valley of Iron County, south of the Wah Wah and Indian Peak ranges, near the rail sidings of Beryl and Zane. Goode (1978) reported a temperature of 149°C (300°F) from a depth of 2,134 m (7,000 ft) measured within a 3,748 m- (12,295 ft-) deep well that he termed "De Armand #1." Goode also reported that, upon testing, the well flowed at a rate of 3,785 L/min (1,000 gpm) and that the water contained less than 4,000 mg/L TDS. No flowing temperature was given. According to records obtained from the Utah Division of Water Rights, three companies B "McCulloch Oil Corporation (MCR Geothermal Corp.), Geothermal Kinetics, Inc., and Utah Power & Light Company" B formed a partnership to drill and complete a well referred to as "MCO-GKI-UPL-DeArman #1." The well was located in the SW¼, SE¼, SW¼, section 18, T.34S., R.16W. and drilled during the spring of 1976. Documents filed with the Division of Water Rights during December of 1981 and correspondence dated November 12, 1985, suggest that the well was drilled to a depth of at least 2,361 m (7,745 ft) and that it did not comply with state-regulated abandonment procedures at that time.

Klauk and Gourley (1983) made no mention of the above-referenced ("DeArman") well, but reported a temperature of 60°C (140°F) measured at a depth of 2,461 m (8,072 ft) within an unnamed geothermal test well located in the NE¼, NE¼, NW¼, section 22, T.34S., R.16W. This location corresponds to a well reportedly drilled in 1976 by MCR Geothermal Corp., and referred to as "State #1" (letter from Utah Division of Water Rights to Insurance Company of North America, dated November 12, 1985).

Wood's Ranch is located just south of the Wah Wah Mountains in the northwest part of the Escalante Valley in Iron County (figure 4). One of two wells, a 61-m (200-ft) deep water well drilled for irrigation on the ranch produces 36.5°C (97.7°F) water. No hot springs are present. A self-potential survey performed by workers from the University of Utah and the UGS (Ross and others, 1991b) revealed a broad, negative SP anomaly interpreted as thermal up-flow. Beyond the SP survey and one water analyses, no exploration has been carried out on the property. Chemical geo-thermometers suggest reservoir temperatures in the range of 100° to 115°C (212° to 239°F). The warm water produced from the well may be a mixture of thermal water and non-thermal ground-water from the Escalante Valley aquifer. The area is somewhat remote with no incorporated communities nearby. The Union Pacific rail line crosses the Escalante Valley within 1.6 km (1 mi) of Wood's Ranch. Access roads into the area are both improved county and BLM roads, and jeep trails. Land ownership in the vicinity of the thermal wells is private. Surrounding lands are federal and state owned.

Sanpete and Sevier Valleys

The Sanpete and Sevier Valleys form a long, narrow, northeast-southwest depression in central Utah (figure 17). Although appearing geologically simple, surficial deposits mask a structurally complex area of subsidence caused by faulting, folding, and dissolution of salt from Jurassic formations. Warm springs and wells occur throughout both valleys, although, the hotter springs are located at the southern margin of the Sevier Valley.

Three hot spring areas extend over a distance of about 10 km (6 mi) at the southern end of the Sevier Valley. The springs B Monroe, Red Hill, and Joseph B were originally included in the Monroe-Joseph KGRA. Brook and others (1979) considered Monroe and Red Hill Hot Springs as one system, and considered Joseph Hot Springs a separate, but similar, system. The springs are associated with Quaternary normal faults which offset widespread mid-Tertiary, intermediate volcanic rocks erupted from the Monroe Peak and Mount Belknap calderas, and other sources farther westward (Mabey and Budding, 1994).

Monroe-Joseph Geothermal Area

Monroe Hot Springs and Red Hill Hot Springs are situated less than a 0.8 km (0.5 mi) east of the town of Monroe, a community of about 1,470 people (1990 census) located about 5 km (3 mi) east of Interstate Highway 70 in Sevier County (figure 17). Monroe was the site of a number of geoscience and exploratory drilling studies sponsored by the U.S. Department of Energy in the late 1970's and early 1980's to assess resource potential (Mabey and Budding, 1987). Although feasibility studies based upon fluid temperatures and flow-rates from a DOE-sponsored production well showed that a district-heating system was not economical, the area could be attractive for process or agricultural direct-heat applications.

The Monroe and Red Hill Hot Springs issue at about 77°C (170°F) near the surface trace of the Sevier fault, adjacent to the Sevier Plateau. The Sevier fault is a 482-km (300-mi) long zone of rupture extending from the Grand Canyon northward into central Utah. Chemical geothermometers suggest maximum resource temperatures of about 110°C (230°F). Maximum measured temperature is 77°C (171°F) at Red Hill Hot Springs and 76°C (169°F) at Monroe Hot Springs. Combined flows for the Monroe-Red Hill system have been estimated at about 1,200 L/min (320 gpm).

Joseph Hot Spring discharges from a spring mound near the Dry Wash fault, which parallels the Sevier River along the northwest edge of a group of hills that are part of the Antelope Range. The springs issue at 63°C (145°F) with flow rates approaching 121 L/min (32 gpm).

At Monroe Hot Springs, Mystic Hot Springs Resort uses geothermal water to heat a swimming pool, several therapeutic baths, and for tropical fish ponds. Richfield (population - 5,590 - 1990 census), the county seat of Sevier County is located a few miles to the north along Interstate Highway 70. The Sevier-Sanpete Valley is an agricultural region extending for about 129 km (80 mi) northeastward from the Monroe area. Land ownership in the Sevier Valley is mostly private.

St. George Basin Geothermal Area

The St. George basin geothermal area covers roughly 650 square kilometers (250 mi^2) in extreme southwestern Utah and includes the Santa Clara and Virgin River Valleys in Washington County (figure 18). The area coincides with the St. George basin subprovince of Stokes (1977). The Pine Valley Mountains to the north, the Beaver Dam Mountains to the west, the Hurricane Cliffs to the east, and the Utah-Arizona state line to the south border the basin. The basin lies along the western margin of the Colorado Plateau, just east and south of the Basin and Range - Colorado Plateau

Transition Zone.

Sedimentary strata folded along northeast axes characterize the St. George basin, although many consider the basin as part of the Colorado Plateau. Strata in the region generally dip gently northeastward, and the basin is bordered structurally on the east by the Hurricane fault, and on the west by the Grand Wash-Gunlock fault (Petersen, 1983).

The basin is underlain by a thick sequence of Paleozoic and Mesozoic strata, sandwiched between Precambrian metamorphic rocks, exposed in the Beaver Dam Range, and a series of Tertiary intrusive and volcanic rocks exposed in the Pine Valley and Bull Valley Mountains, respectively. Hamblin (1970) described four stages of Late Cenozoic basalt flows and cinder cones in the St. George basin that form many elongate eroded ridges.

Two major structural trends include northeasterly aligned folds and faults of Laramide age, and post-Laramide north-south oriented extensional faults. The Virgin anticline, a major Laramide feature, extends northeasterly across the center of the basin for about 27 km (17 mi). The Hurricane fault, a post-Laramide feature, is an active normal fault that extends for over 300 mi (482 km) from Cedar City through northwestern Arizona. The Grand Wash-Gunlock fault, which was active during Pleistocene time, can be traced from Gunlock, Utah southward for about 160 km (100 mi) into Arizona. The Washington fault, an active normal fault extending southward from the foothills of the Pine Valley Mountains across the Virgin anticline and into Arizona, nearly bisects the St. George basin (Sommer and Budding, 1994).

Thermal Springs at Pah Tempe Resort

Pah Tempe Hot Springs, also known as La Verkin or Dixie Hot Springs, are located along the Virgin River where the river cuts through Timpoweap Canyon along the Hurricane Cliffs.
The north-trending Hurricane fault lies a short distance west of the springs. The springs issue from multiple vents in fractured Permian Toroweap Limestone. Widespread basalt flows ranging in age from 2 million years B.P. to 1,000 years B.P. lie in the vicinity of the springs, possibly relating to local heat sources for the thermal water.

In the mid-1980s, construction of a water pipeline for the Quail Creek (off-line storage) reservoir reportedly disrupted the discharge of existing hot springs and new springs emerged at lower bank-levels along the Virgin River (Ben Everitt, Utah Division of Water Resources, verbal communication, 1993). Flows to the original springs were partly restored after installation of a clay and cement seal in the construction area. In September 1992, a 5.8 magnitude earthquake evidently contributed to another disruption of spring flows as discharge decreased and again new springs emerged at lower bank- levels along the Virgin River (Ken Anderson, Pah Tempe Resort, verbal communication, 1993). Available analyses for the springs, done prior to the earthquake, are variable and possibly reflect differences in sample collection points. Blackett (1994) obtained a post-earthquake spring sample collected from one of the new spring orifices where the Quail Creek pipeline crosses the Virgin River. The post-earthquake sample results were similar to the previous analyses. The water is a sodium calcium-chloride, sulfate, and bicarbonate type. Geothermometers suggest equilibration temperatures between 75°C and 80°C (167°F and 176°F).

Flow rate, chemistry, and temperature have varied through time. Mundorff (1970), and Sommer and Budding (1994) reported that temperatures recorded at the springs have varied over the last 100 years from 38° to 56°C (100° to 133°F). It is not clear whether the spring temperatures have declined over the past century or if the earlier temperatures recorded were inaccurate. Recent measurements have shown the springs to issue at temperatures near 42°C (108°F). Flow rates measured by several workers suggest that the combined flows for all of the vents range between 17,000 and 19,000 L/min (4,500 and 5,000 gpm). Pah Tempe Springs are relatively high TDS content, ranging between 8,390 and 9,340 mg/L.

Veyo Hot Spring

Veyo Hot Spring is located southeast of the town of Veyo along the Santa Clara River. Here the river has incised 1 and 2 million-year-old basalt flows to form a steep-walled canyon. Mundorff (1970) reported that spring temperatures ranged from 32° to 37°C (90° to 97°F), TDS values ranged from 389 to 402 mg/L, and the flow rate was constant at 456 L/min (120 gpm). Budding and Sommer (1986) reported a temperature measurement of 29.5°C (85°F).

Other St. George Basin Thermal Springs

A warm spring, locally referred to as Washington Hot Pot, located north of Washington City fills a circular depression about 9 m (30 ft) in diameter with a maximum depth of 1.5 m (4.9 ft). The spring is in the Navajo Sandstone and is a little over 1 km (0.6 mi) west of the Washington fault. A temperature of 24.5°C (76°F) was measured in February 1986 and a water sample contained a calculated dissolved solids content of 311 mg/L. Budding and Sommer (1986) recorded a temperature of 23°C (73°F) at Green Spring, located 1.2 km (0.7 mi) west of Washington Hot Pot. Budding and Sommer (1986) also measured a temperature of 20°C (68°F) at West St. George Spring, located near the northwest edge of the city, and an unnamed spring just northwest of Interstate Highway15 between Washington and Middleton. Washington City Spring, about 1 km (0.6 mi) east of the hot pot, issues at 19.5°C (67°F).

Thermal Wells in the St. George Basin

Sommer and Budding (1994) reported the results of temperature measurements and water chemistry for 17 water wells in the St. George Basin. Temperatures in the wells ranged from 19.5 to 40°C (67° to 104°F) with the warmer wells located north of St. George and Washington City. Dissolved solids content in these wells ranged from 120 to 1,360 mg/L and the warmer wells contained higher TDS values.

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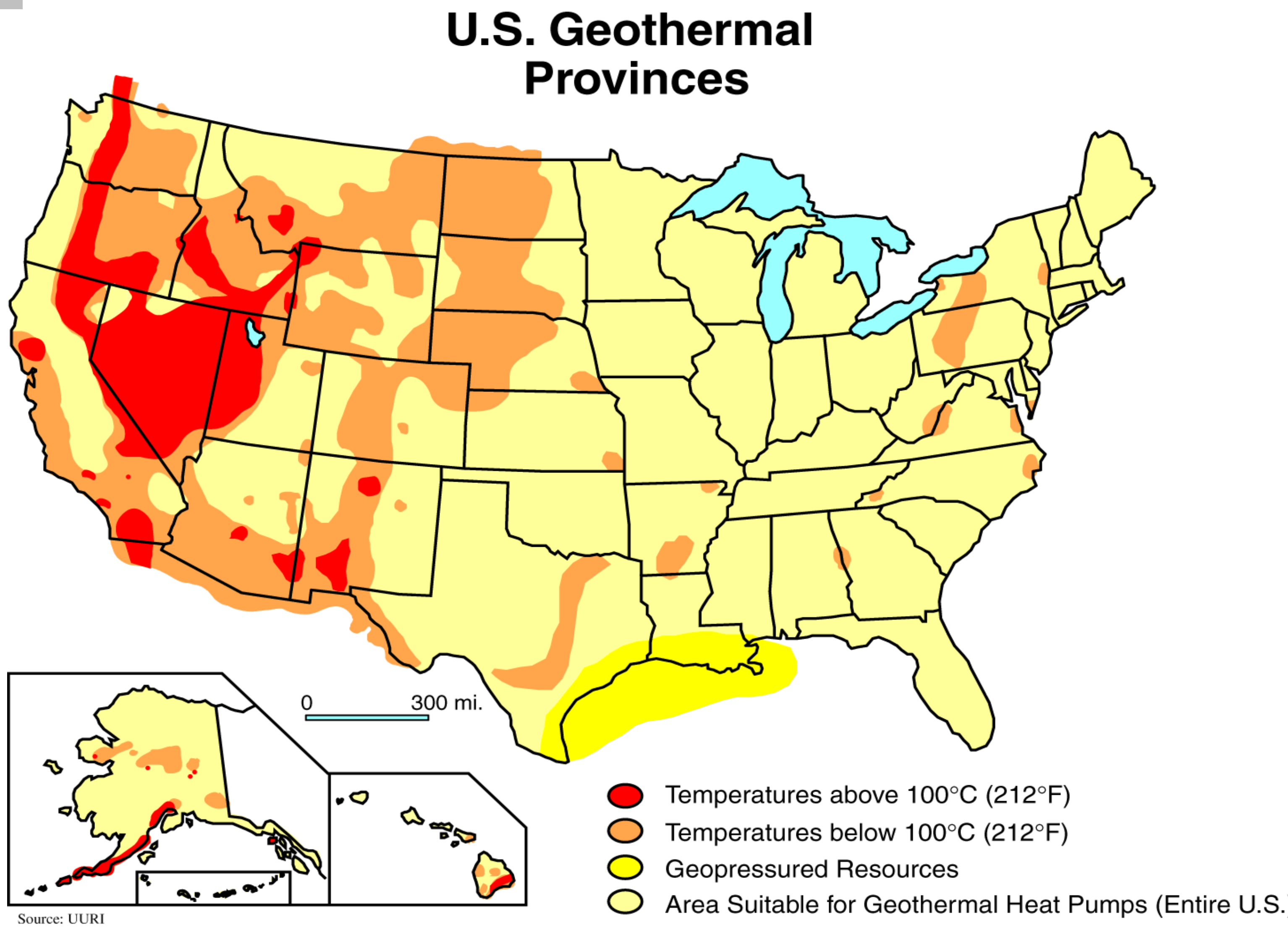

Figure 1. Geothermal resource map of the United States showing general areas of occurrence and resource type (from Energy and Geoscience Institute, University of Utah).

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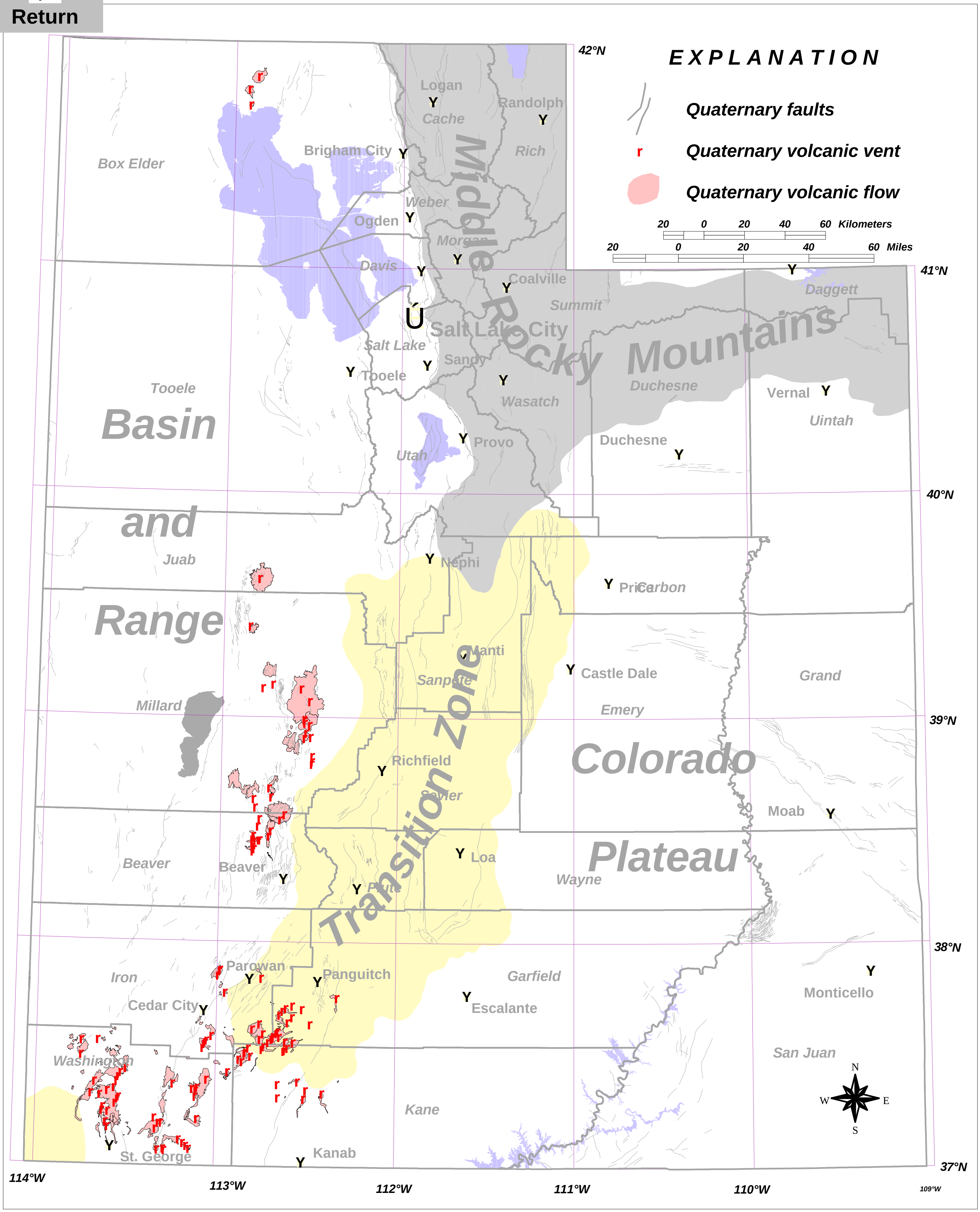

Figure 2. Physiographic provinces, Quaternary faults, Quaternary volcanic rocks, and Quaternary volcanic vents in Utah (after Stokes, 1977; Hecker, 1993; and Black and others, 2000).

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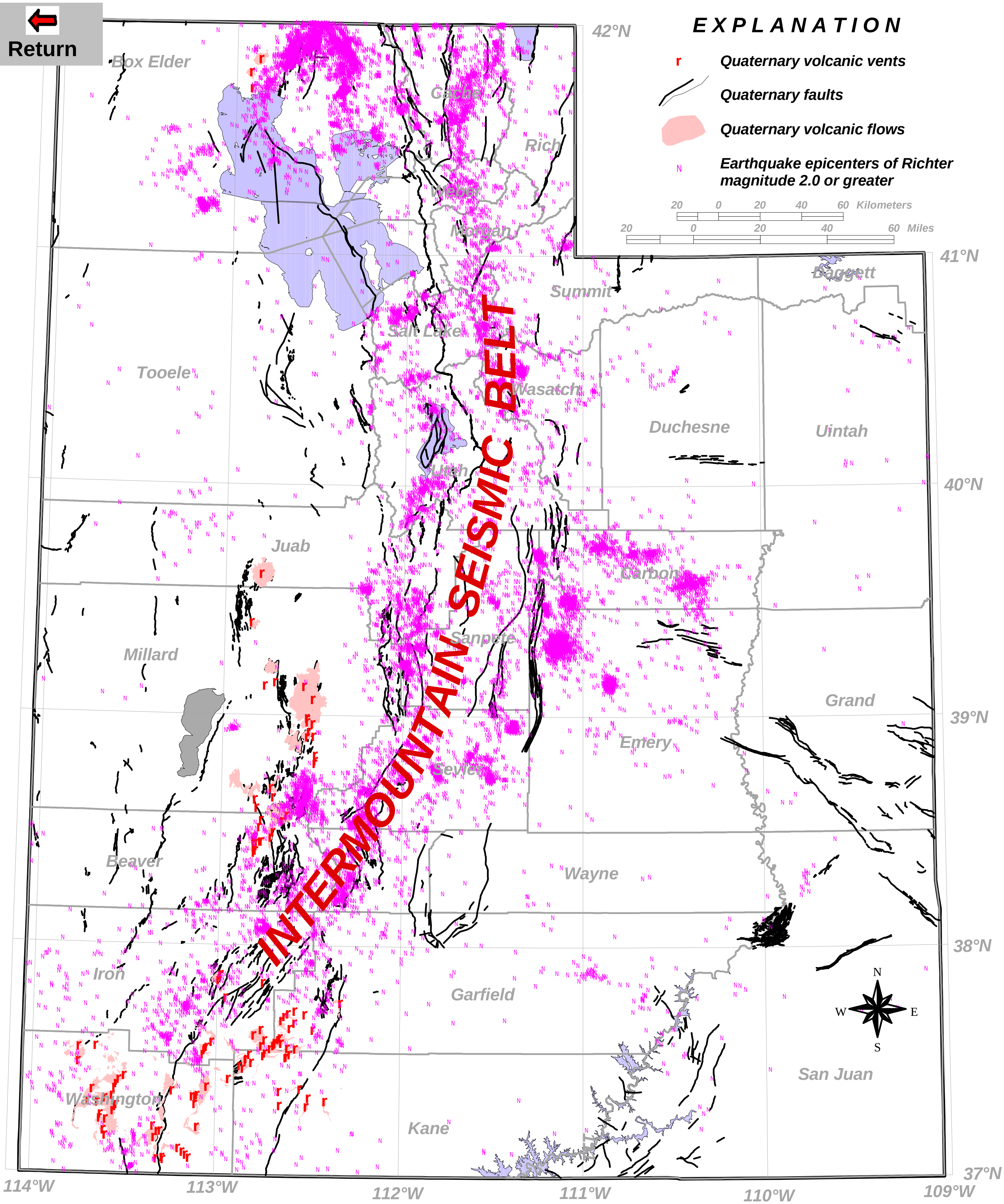

Figure 3. Earthquake epicenters and Quaternary tectonic features in relation to the Intermountain seismic belt (after Smith and Sbar, 1974; Hecker, 1993; and Black and others, 2000).

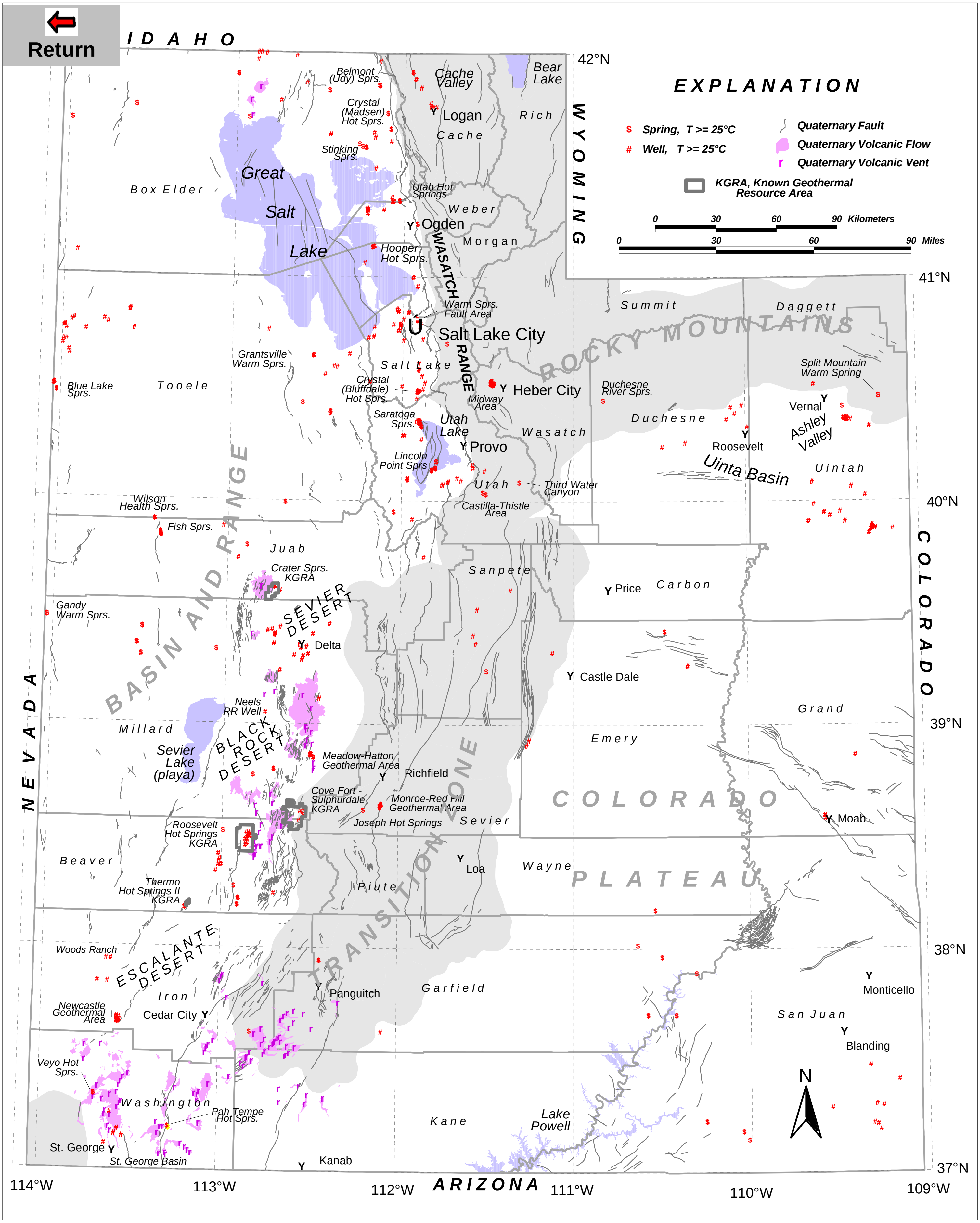

Figure 4. Geothermal resources of Utah showing thermal wells and springs, Quaternary tectonic and volcanic features, and major physiographic regions.

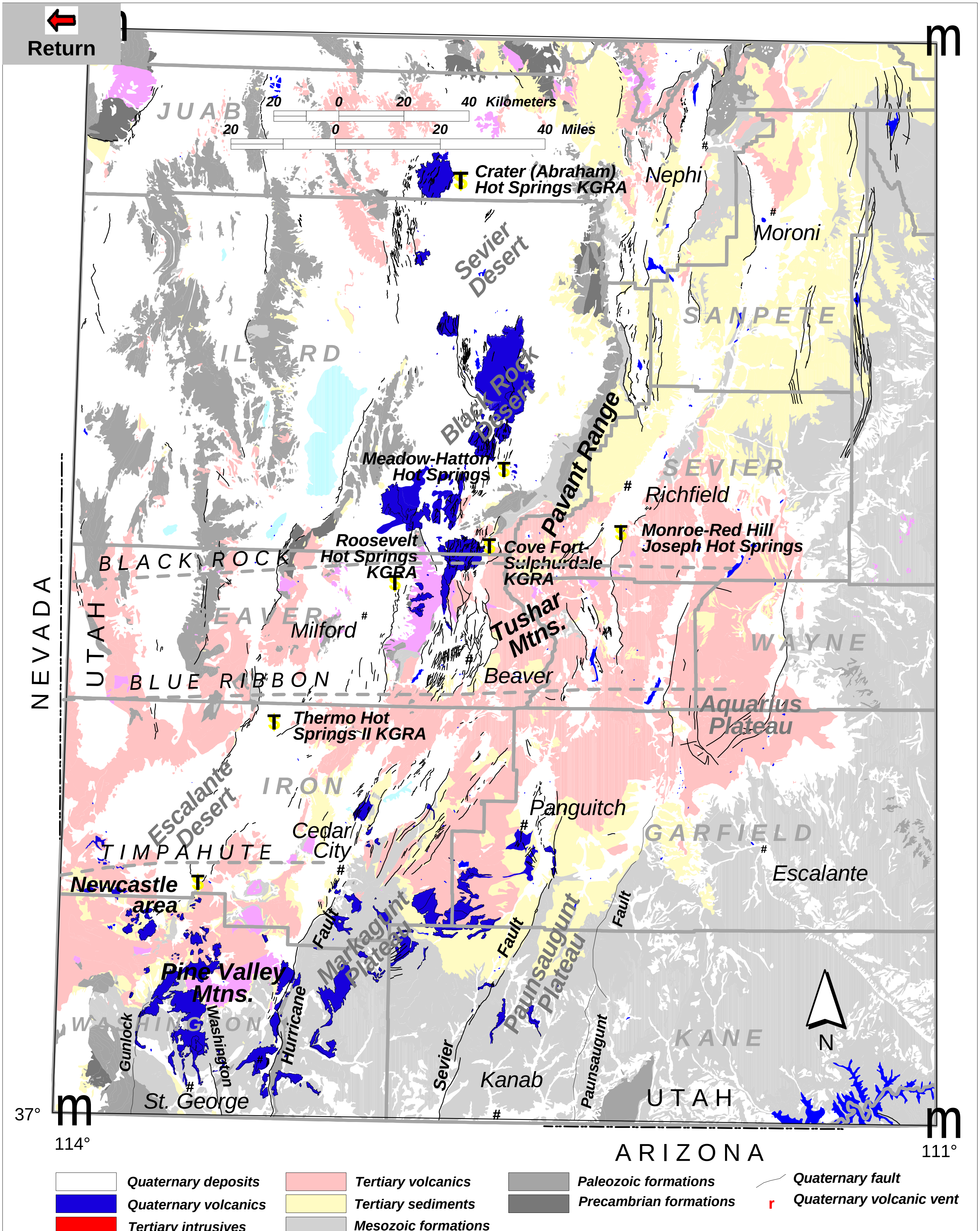

Figure 5. Southwestern Utah's "Sevier thermal area" showing locations of principal geothermal areas, general geology, Quaternary faults, and Quaternary volcanic features. East-west dashed lines approximate the trends of (from north to south) the Black Rock, Blue Ribbon, and Timpahute lineaments (modified from Magey and Budding, 1987; Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

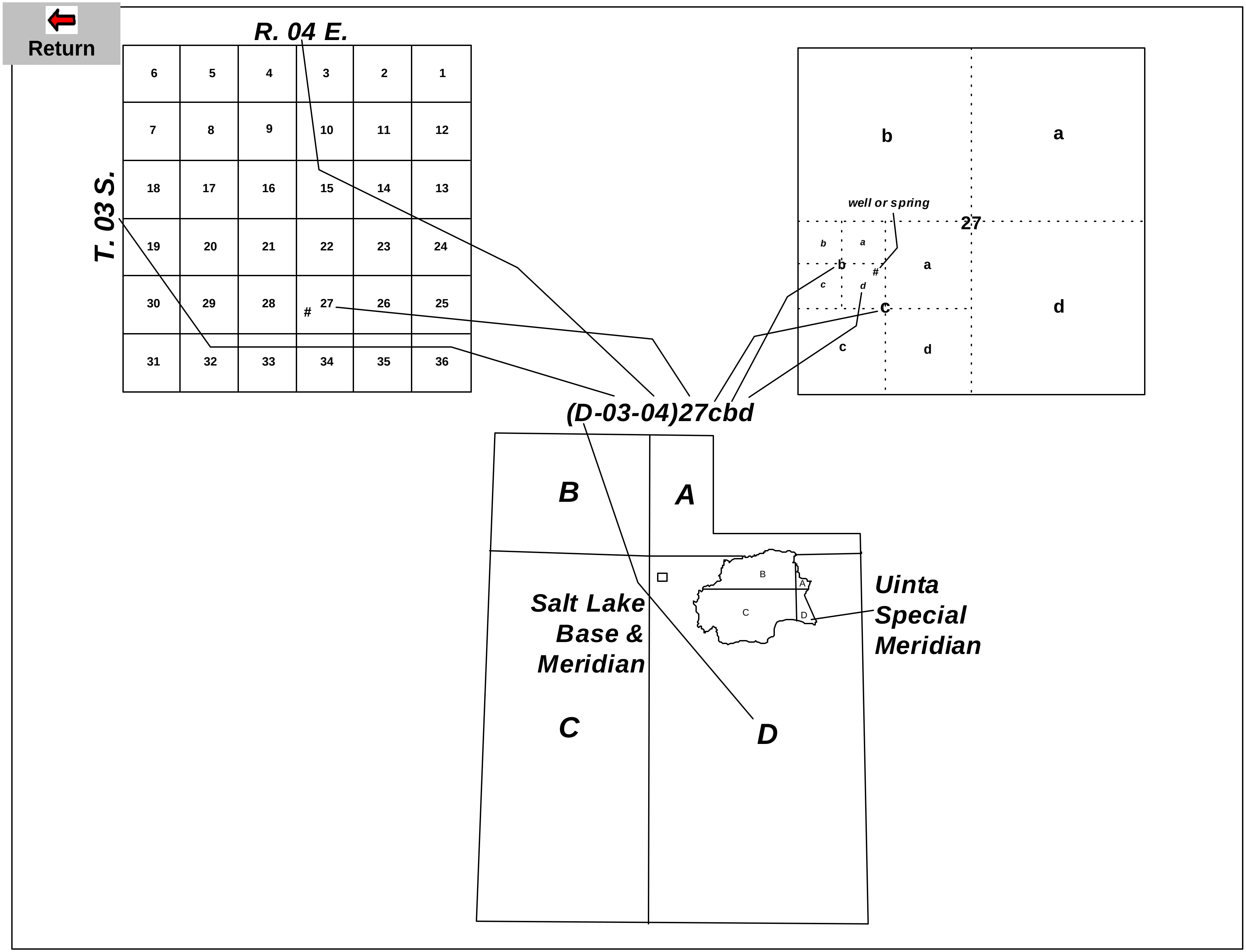

Figure 6. Well and spring numbering system in Utah.

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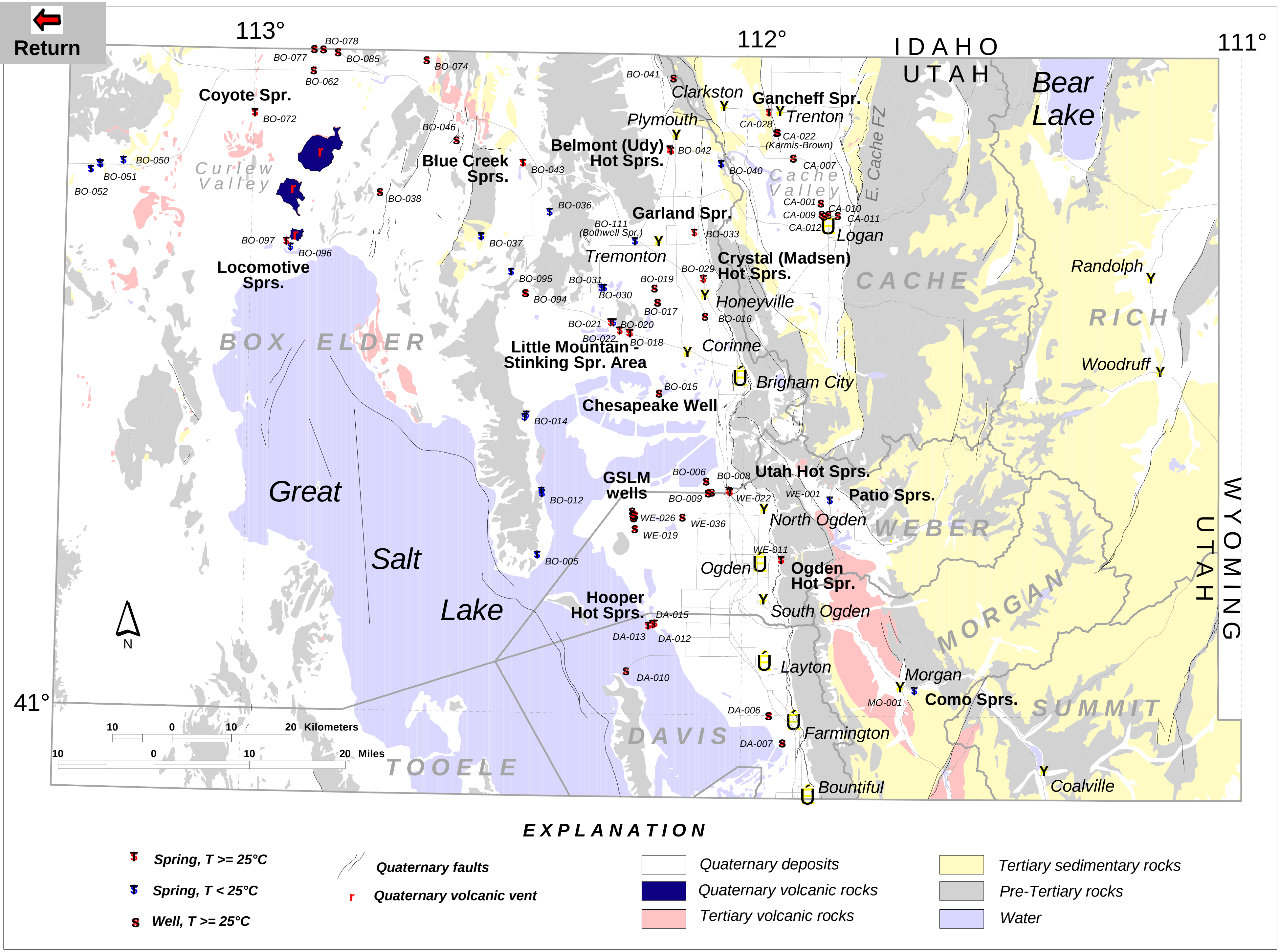

Figure 7. General geology, thermal wells, and springs within the northern Great Salt Lake and northern Wasatch Front region (modified from Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

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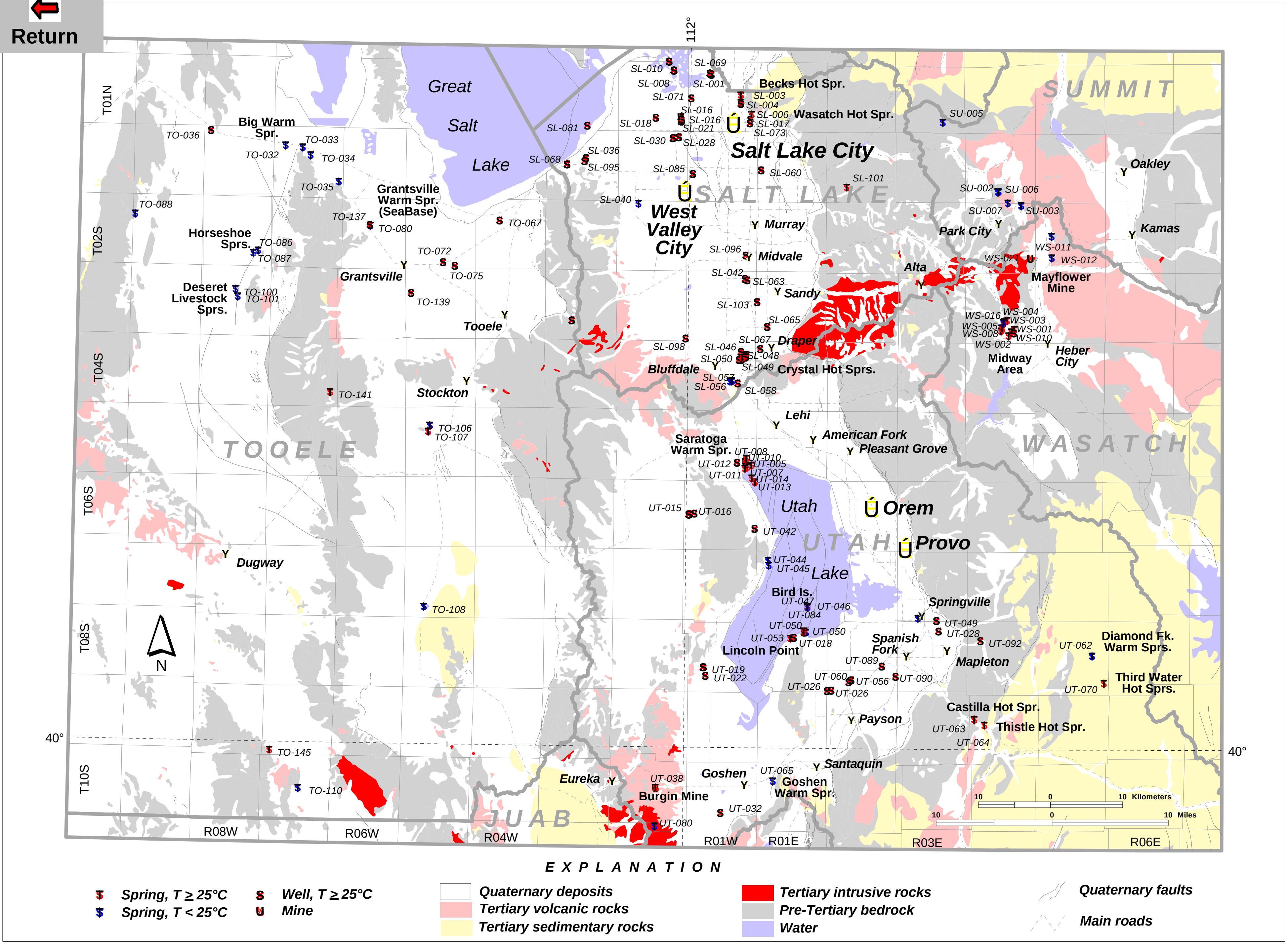

Figure 8. General geology, thermal wells, and thermal springs within the southern Wasatch Front region (modified from Black and others, 2000; and Hintze and others, 2000).

Figure 9. Photo of a basaltic tuff cone within a 14,300 year-old volcanic crater at Tabernacle hill in the Black Rock Desert of Millard County.

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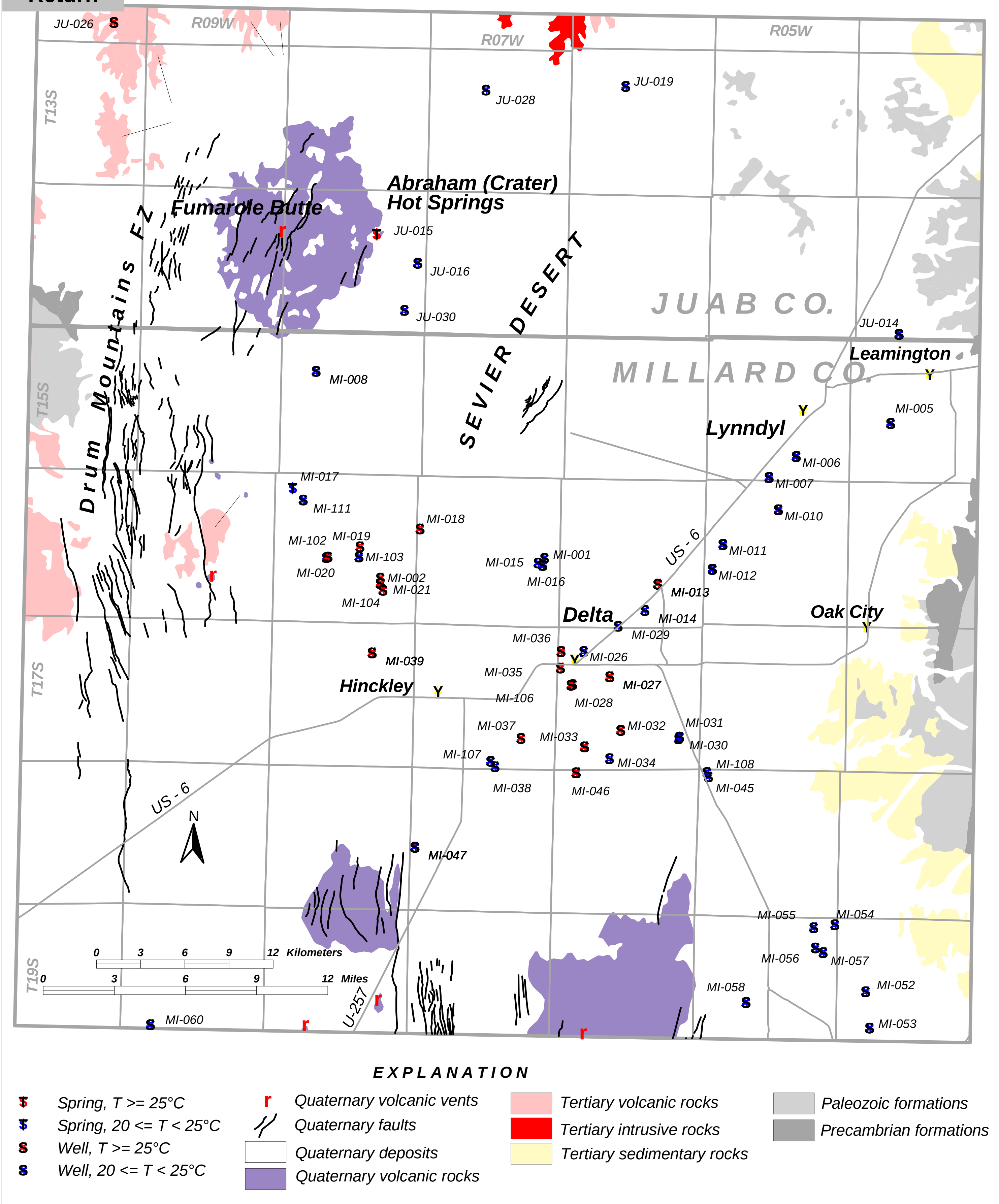

Figure 10. General geology and geothermal sources in the northern Sevier Desert, Millard and Juab Counties, Utah (modified from Hecker and others, 1993; Black and others, 2000; and Hintze and others, 2000).

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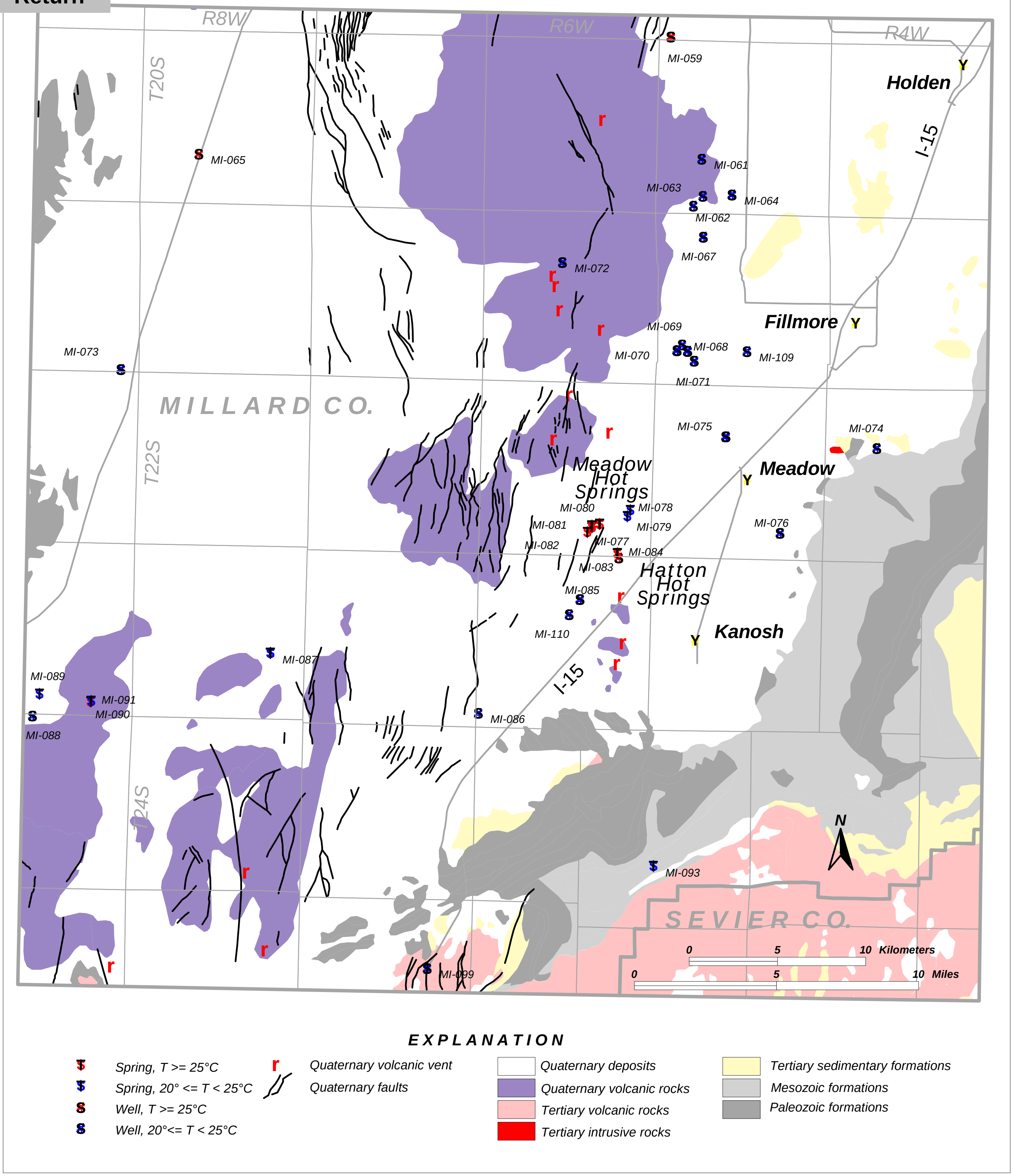

Figure 11. General geology and geothermal sources in the southern Sevier Desert and Black Rock Desert, Millard and Sevier Counties, Utah (modified from Hecker, 1993, Black and others, 2000; and Hintze and others, 2000).

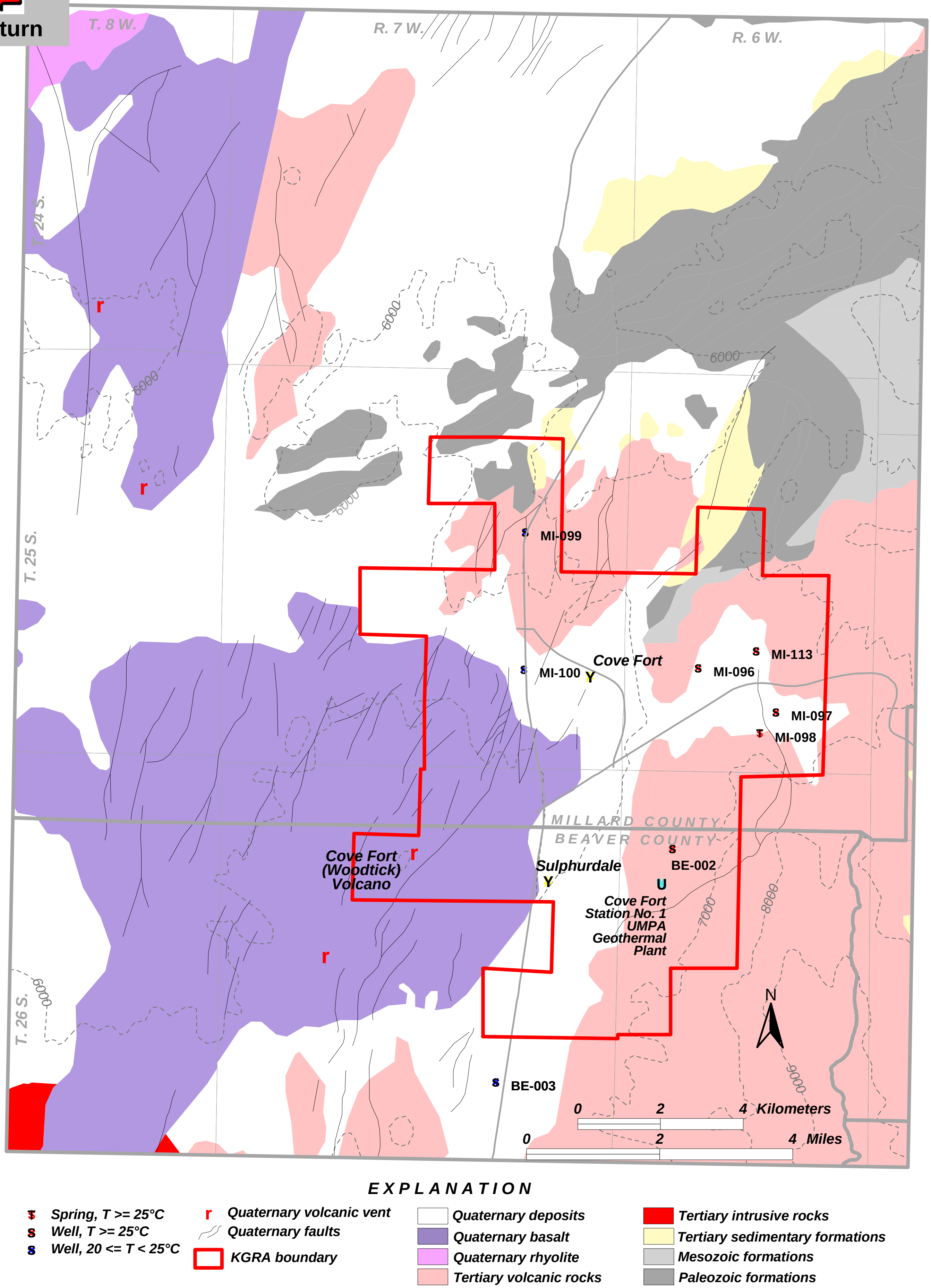

Figure 12. General geology and geothermal sources of the Cove Fort-Sulphurdale KGRA and vicinity, Millard, Beaver, and Sevier Counties, Utah (modified from Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

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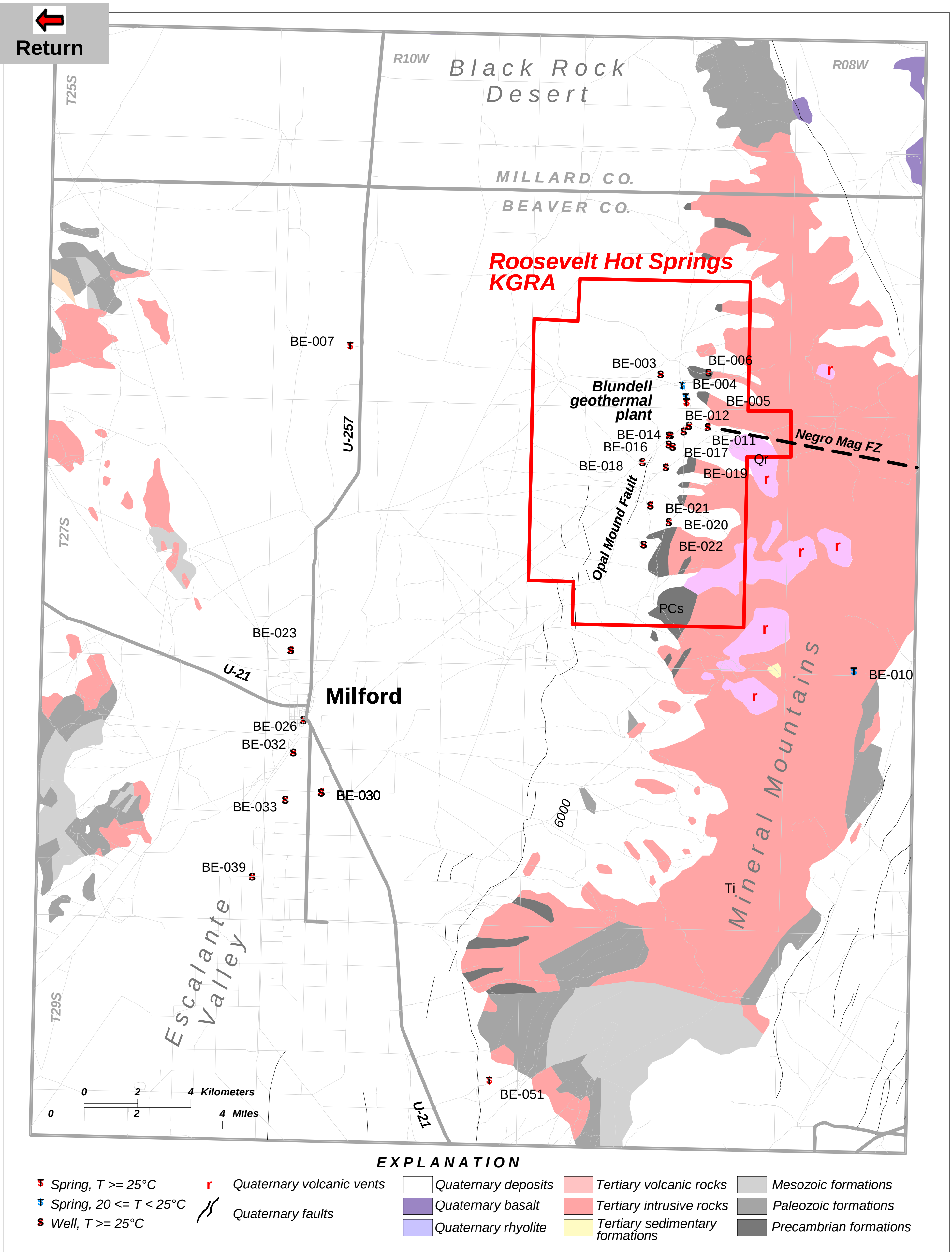

Figure 13. General geology and geothermal sources of the Roosevelt Hot Springs KGRA and vicinity, Beaver and Millard Counties, Utah (modified from Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

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Figure 14. Photo of Utah Power's Blundell geothermal power plant at Roosevelt Hot Springs geothermal area near Milford.

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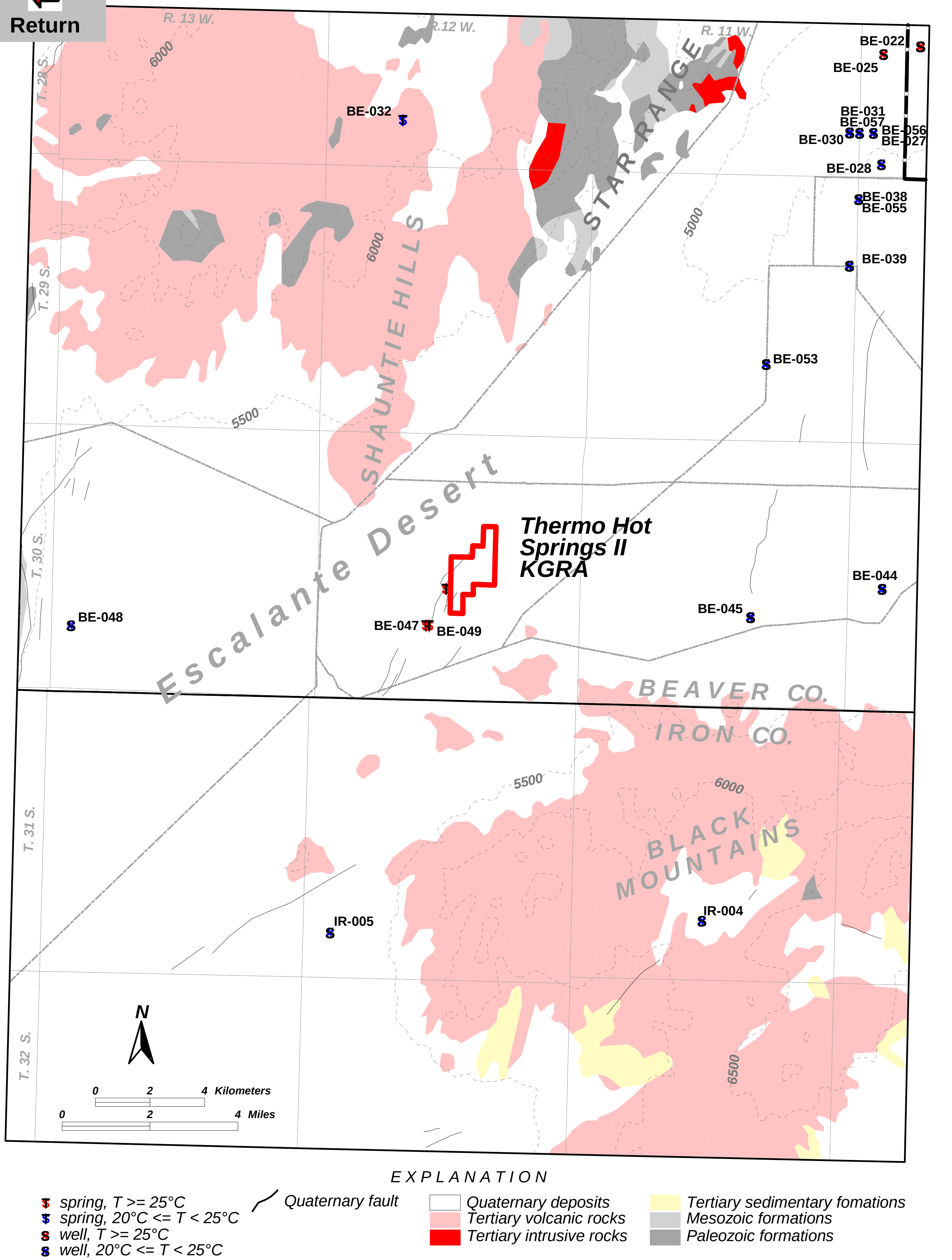

Figure 15. General geology and geothermal sources of the Thermo Hot Springs II KGRA and vicinity, Beaver and Iron Counties, Utah (modified from Black and others, 2000; and Hintze and others, 2000).

Figure 16. General geology and geothermal sources of the Newcastle geothermal area and vicinity, Iron County, Utah (modified from Black and others, 2000; and Hintze and others, 2000).

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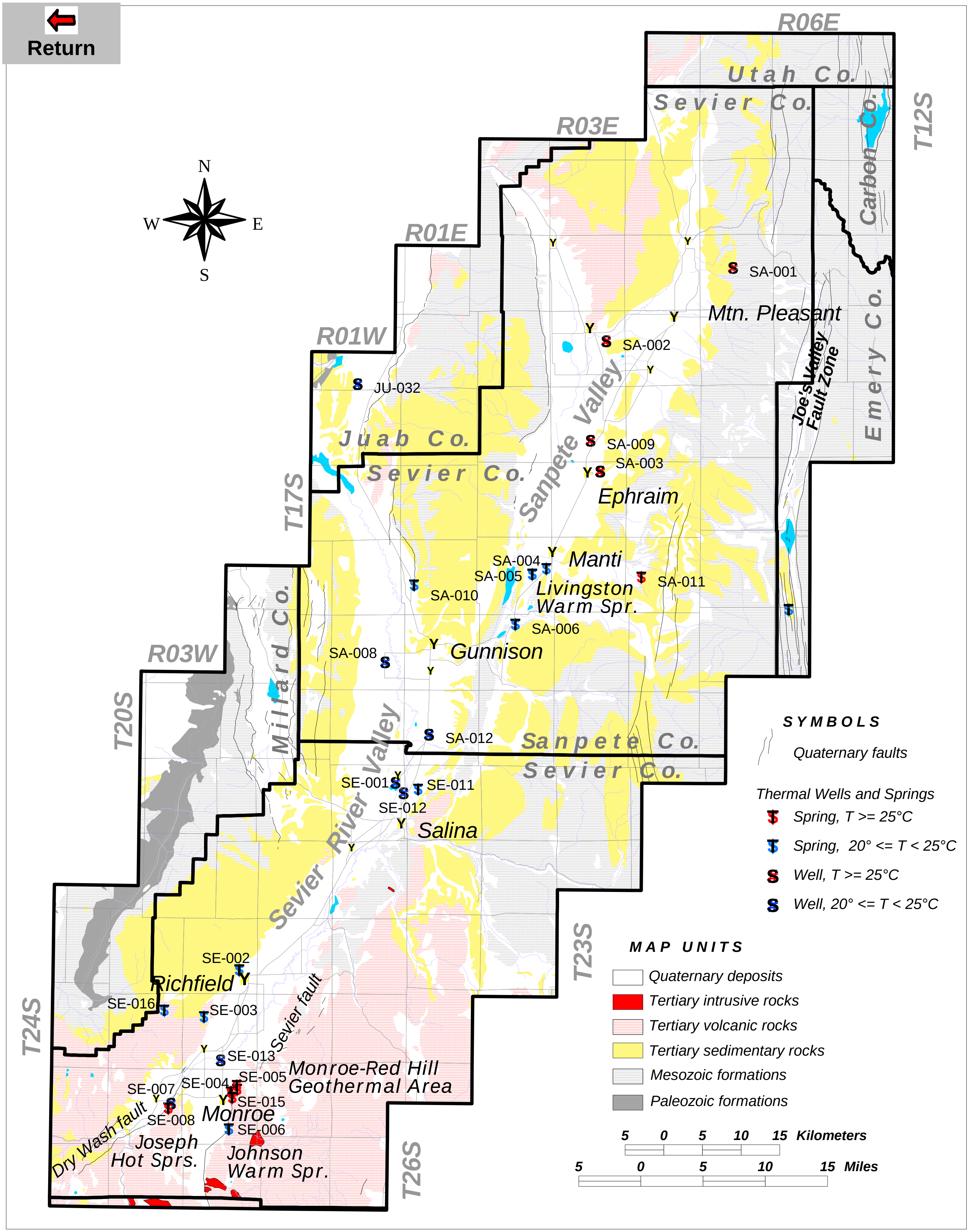

Figure 17. General geology and geothermal sources of the Sanpete and Sevier Valleys and vicinity, Sanpete and Sevier Counties, Utah (modified from Black and others, 2000; and Hintze and others, 2000).

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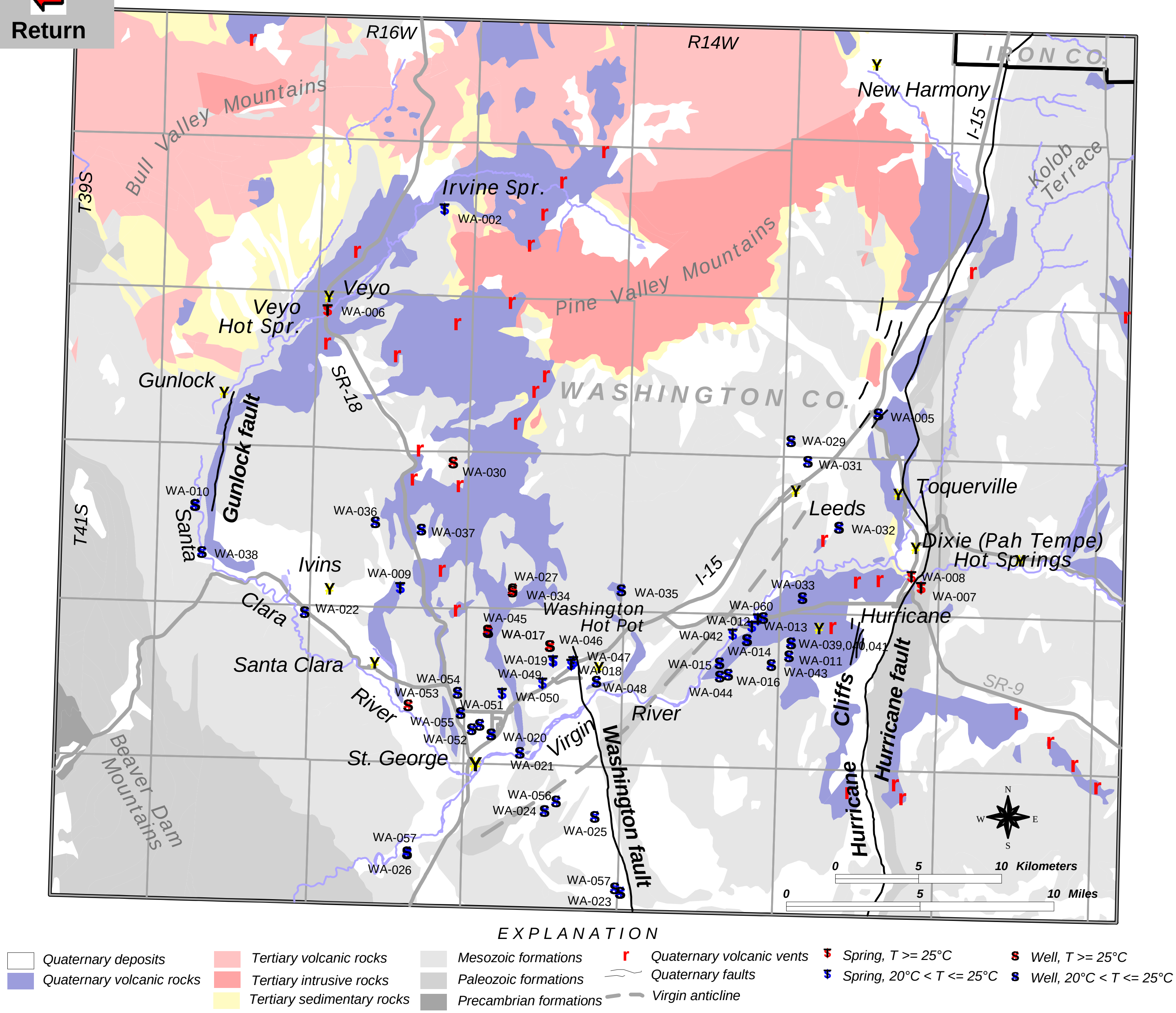

Figure 18. General geology and geothermal sources of the St. George basin geothermal area and vicinity, Washington County, Utah (modified from Hecker, 1993; Hintze and others, 2000; and Black and others, 2000).

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Table 1. Geothermal resource classification (modified from White and Williams, 1975)

Resource Type	Temperature Characteristics
Convective Hydrothermal Resources	
vapor dominated	~ 240°C
hot-water dominated	~ 30°C to 350°C
Conductive Hydrothermal Resources	
High Plains deep regional aquifers sedimentary basins	~ 40°C to 150°C
Gulf Coast geopressured basins	~ 90°C to 200°C
Atlantic Coastal Plain buried radiogenic plutons	~ 30°C to 150°C
Hot Rock Resources	
partially molten (magma)	> 600°C
solidified (hot, dry rock)	~ 90°C to 650°C

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Table 2. Explanation of data-fields included within the GIS coverage of Quaternary faults and folds in Utah (from Hecker, 1993).

FIELDNAME	FIELD CONTENTS
LOCNUM UGS:	location number
FEATURE:	1 = fault, 2 = anticline, 3 = syncline, 4 = monocline
TYPE:	1 = surface, 2 = inferred/approximate, 3 = buried/concealed, 4 = hypothetical, 5 = plunging
AGE:	Probable age of most recent movement 1 = Holocene (red) 1 - 30,000 ya 2 = Late Pleistocene (orange) 10,000 - 130,000 ya 3 = Mid to Late Pleistocene (green) 10,000 - 750,000 ya 4 = Early to Mid Pleistocene (purple) 130,000 - 1,650,000 ya 5 = Quaternary (black) < 1,650,000 ya
RUPTURE:	Relative likelihood of displacement of ground surface by faulting: 1 = high, 2 = moderate to high, 3 = moderate, 4 = low to moderate, 5 = low, 6 = very low
NUMBER:	Assigned by USGS within Western Hemisphere Database
NAME:	Common name of fault/fold in the geologic literature
USGSAGE:	Time of most recent paleoevent on fault feature 1 = Historic (red) a specific year 2 = Holocene and Post-Glacial (orange) < 15 Ka 3 = Late Quaternary (green) < 130 Ka 4 = Mid to Late Quaternary (blue) < 750 Ka 5 = Quaternary (black) < 1.6 Ma
SLIPRATE:	Average activity on fault feature, amount of movement: A = > 5 mm/yr, B = 1 - 5 mm/yr, C = < 1mm/yr
RELIABILITY:	Continuousness of feature: X = continuous (solid line);Y = discontinuous (dashed line); Z = concealed (dotted line).
MOVEMENT:	Principal sense of movement of faults: N = normal, NS = normal/sinistral, S = sinistral T = thrust, R = reverse, O = oblique, D = dextral
SCALE:	Scale denominator of source map

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Table 3. Explanation of data-fields included within the GIS coverages for Quaternary volcanic flows and vents in Utah (from Hecker, 1993).

FIELDNAME	FIELD CONTENTS
LOCNUM UGS:	location number
FEATURE:	7 = volcanic flow; 8 = volcanic vent
TYPE:	not applicable
AGE:	Probable age of most recent activity: 1 = Holocene (red) 1 _ 30,000 ya 2 = Late Pleistocene (orange) 10,000 _ 130,000 ya 3 = Mid to Late Pleistocene (green) 10,000 _ 750,000 ya 4 = Early to Mid Pleistocene (purple) 130,000 _ 1,650,000 ya 5 = Quaternary (black) < 1,650,000 ya

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Table 4. Cutoff temperatures applied to geothermal wells and springs in Utah counties.

County	Cutoff Temp (°C)	County	Cutoff Temp (°C)
Beaver	20	Piute	20
Box Elder	20	Salt Lake	20
Cache	18	San Juan	20
Carbon	20	Sevier	20
Davis	20	Sanpete	19
Duchesne	18	Summit	18
Emery	20	Tooele	19
Garfield	19	Uintah	18
Grand	20	Utah	20
Iron	20	Wasatch	18
Juab	20	Washington	20
Kane	20	Wayne	20
Millard	20	Weber	20
Morgan	19		

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Table 5. Utah geothermal database (UTAHGEO.dbf), data field summary.

FIELD NAME	FIELD CONTENTS	UNITS
------------------------ *Descriptive Data* --		
ID	unique record ID	number
MAPNO	map number (see table 6)	County code + number
COUNTY	county	NA
SOURCE	well/spring name or designation	NA
LOCATION	well and spring numbering system for Utah	cadastral coords.
IDNAME	USGS naming convention	Lat(dms)/Long(dms)
TYPE	well (W), spring (S), oil-field drain (D) mine (M), collector (C)	NA
TEMP	measured temperature	degrees Celsius
CLASS	classification for 25°C < T, T $\geq$ 25°C	see footnote[1]
DEPTH	depth of well	meters
FLOW	flow rate	liters per minute
LONG	longitude west	decimal degrees
LAT	latitude north	decimal degrees
UTME	UTM east coordinate for zone 12	meters
UTMN	UTM north coordinate for zone 12	meters
LEVEL	depth to water level (negative if above ground)	meters
STATUS	pumped (P), flowing (F)	NA
DATE	date of sample (if available)	mm/dd/yy
REFERENCE	short citation for source of data	NA
------------------------ *Fluid Chemistry Data* ---		
PH	pH	pH units
COND	conductivity	microseimens
NA	sodium	mg/L
K	potassium	mg/L
CA	calcium	mg/L
MG	magnesium	mg/L
AL	aluminum	mg/L
FE	iron	mg/L
SIL	silica (SiO_2)	mg/L
B	boron	mg/L
LI	lithium	mg/L
BIC	bicarbonate (HCO_3)	mg/L
SULF	sulfate (SO_4)	mg/L
CL	chloride	mg/L
F	fluoride	mg/L
AS	arsenic	mg/L
TDSM	TDS measured	mg/L
TDSC	TDS calculated	mg/L
CHGBAL	charge balance	(cations/anions)x100

[1] WELHI, SPRHI $\geq$ 25°C; WELLO, SPRLO < 25°C

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Table 6. List of county codes used in "MAPNO" field[1].

Code	County	Code	County
BE	Beaver	PI	Piute
BO	Box Elder	SL	Salt Lake
CA	Cache	SJ	San Juan
CR	Carbon	SE	Sevier
DA	Davis	SA	Sanpete
DU	Duchesne	SU	Summit
EM	Emery	TO	Tooele
GA	Garfield	UI	Uintah
GR	Grand	UT	Utah
IR	Iron	WS	Wasatch
JU	Juab	WA	Washington
KA	Kane	WY	Wayne
MI	Millard	WE	Weber
MO	Morgan		

[1]No thermal springs or wells were recorded in Daggett and Rich Counties.